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SYMPOSIUM ON SOIL FERTILITY HELD AT BANARAS HINDU UNIVERSITY ON 25th FEBRUARY, 1967

Soon after the foundation of the National Academy of Sciences, India in 1930, the most vital problem of the world *i.e.* feeding its teeming millions has been tackled on many occasions. Prof. N. R. Dhar in his presidential addresses delivered in December, 1935 and January, 1937 initiated the problem of nitrogen fixation and soil fertility improvement by the application of molasses and other organic substances, which also retard the loss of nitrogen from soils. In 1955 in the 25th Jubilee session an important symposium was held on "Recent trends in soil investigations". Also in 1958 an International symposium was held on the "Value of phosphates". In his general presidential address to the Indian Science Congress in Roorkee in 1961 he emphasised that the population explosion was more dangerous than the atomic or hydrogen bomb. Since then acute food shortage has become the order not only in India but in other poor countries as well. Even in Europe food prices specially meat, cheese have gone up enormously.

In the International Soil Science Conference held in the University of Aberdeen in September, 1966 it was declared that by 1999 the world population is likely to go up to 6000-6200 millions (present world population is 3200 millions) and 800 millions may die of starvation.

In order to face the situation the fertility and the productive power of soil must increase. In 1965 an International Soil Fertility Symposium was held in Khartoum (Africa) and the National Academy of Sciences organised a symposium on alga and land fertility.

The Council of the National Academy of Sciences very wisely organised an International Symposium on Soil Fertility in February last year at Banaras under the guidance of N. R. Dhar who received considerable support from Dr. S. P. Raychaudhuri of New Delhi and S. C. Mandal Director of agriculture Bihar. The response of contributors was excellent and the papers read and discussed are being published now.

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Soil Fertility

By

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The Oxford Dictionary meaning of the word 'fertile' is—bearing bountifully, fruitful.

According to Russell the various properties that make up soil fertility are as follows :

1. Adequate amounts of water, air and nutrients must be present in the soil to ensure the fullest growth permitted by the surrounding temperature. Air and water are complementry quantities, both have to fit into the pore space of the soil and any increase in one automatically reduces the other. The amount of pore space is determined by the size and distribution of soil particles. Water is adsorbed by the soil colloids and is held near the soil surface.

2. The plant has to obtain the air water and nutrients as fast as is demanded by its continuous growth rate.

Calcium Compounds and soil fertility.

3. The plant root has to pass through the medium easily, *i.e.* the soil must be porous, and, this is achieved by a proper flocculation of the soil colloids. Calcium has a unique position amongst plant nutrients in determining soil fertility, because, calcium clay is most favourable for the growth of plants, magnesium, sodium and acid clays being much inferior.

Russell has stated that it is easier to investigate infertility than fertility because infertility is presented as a specific problem.

In humid climates, farmers increase the productiveness of their soils by the application of fertilizers, ploughing in of green crops and feeding animals nitrogen-rich oil cakes on the land.

Calcium carbonate and animal dung formed the basic ingredients in land manuring in Europe till the beginning of the 20th century, but the part played by dung was not properly understood. On the other hand, the function of chalk in soil fertility is well known. Calcium carbonate and lime are largely used in neutralising soil acidity and saturating the clay and humus complexes with calcium. In presence of lime, a part of the soil silicates and humus takes up the OH ions and may pass into the colloidal state. But, the bivalent calcium ion obtained from calcium carbonate coagulates the soil colloids. Due to the washing away of calcium carbonate caused by the formation of calcium bicarbonate from temperate country soils, the application of chalk, marl and lime has played an important part in agriculture.

According to Hilgard, for obtaining best results in crop production, sandy soils should not possess less than 0·1% and heavy clay soils 0·6% calcium carbonate. Normally, 2—3% calcium carbonate in a soil provides the optimum conditions for plant production. Farmers in the developed countries generally believe in

the truth of the adage : "The lime country is a rich country." In Germany and other parts of Europe, it was frequently stated that "Lime and lime without manure makes both farm and farmer poor." The chief functions of lime and calcium carbonate are as follows :

(*a*) Supply of the important plant nutrient, calcium.

(*b*) Neutralising the acidity.

(*c*) Forming soluble calcium salt which readily coagulates the negatively charged silicic acid sol, silicates and humus and this leads to the increase in porosity of the soil and improvement in its texture.

(*d*) Being feebly alkaline, it helps the oxidation of humus with liberation of ammonia, nitrate, phosphate and other plant nutrients.

(*e*) It produces calcium phosphates from aluminium, iron and titanium phosphates, which are very sparingly soluble and are present in acid soils.

The calcium phosphate formed can be converted into more soluble calcium, di- and mono- phosphates by the action of carbonic acid present in the soil.

Dhar and co-workers have observed another important function of calcium carbonate, *i.e.* in fixing atmospheric nitrogen in the soil from the slow oxidation of carbohydrates and other energy materials present in the soil or added to it.

In this connection the following observations of Russell are of interest :

"As a general rule, though with many exceptions, the percentage of nitrogen varies with that of lime, and the high moor contains least of these, the low moor a larger quantity and the fens a still larger quantity :

		Nitrogen % in dry matter	CaO% in dry matter	Observer
High moor.	Bremen	1·14	0·44	Tacke.
	Lancashire	0·85	0·11	Russell and Prescott.
Low moor.	Bremen	1·62	1·24	Tacke.
	Cheshire	0·91	0·16	Russell and Prescott.
Fen.	Norfolk	2·85	7·5	,, ,, ,,

A sample of Swedish peat analysed by Dhar and Singh showed CaO. 1·85% and N 1·936%.

One of the distinguishing characteristics of a soil is that it contains a part of the complex material photosynthesised by plants. It is believed that this material supplies energy to the soil micro-organisms and we may look upon the soil organic matter as taking part in a cycle of operations.

In one stage, the decomposed soil organic matter nourishes the growing plant which is the storehouse of solar energy. The soil organic matter causes the soil to assume a dark-brown or black colour. It is well known that farmyard manure by its decomposition and oxidation in soils gives out CO_2 and the soil loosens and avoids stickiness. The cellulose and lignin added to the soil and other organic

matters undergo partial oxidation and form complex colloidal substances containing one or more COOH group. These colloids are negatively charged and possess strong adsorptive power for water and positive ions. It is well known that the adsorptive power of humic acid is 4 times greater than that of the negatively charged silicic acid sol. Consequently, when inorganic fertilizers like ammonium salts, potassium salts are added to a soil rich in humus, the inorganic salts are saved from leaching due to their adsorption on the colloids and that is why, all over the world, the value of inorganic fertilizers has been found to be more favourable in humus-rich soils than in the humus-poor soils. Moreover, the sparingly soluble phosphates of Ca, Mg etc. are rendered soluble and become available to crops by the carbonic and weak organic acids produced from the slow oxidation of organic matter. Also, the organic acids produced can appreciably dissolve chiefly by forming complex ions with very sparingly soluble phosphates of ferrous, ferric, aluminium, titanium, zirconium etc. It is well known that in the presence of soil humus iron cannot be detected by potassium ferrocyanide solution because the iron forms a complex with the humus organic acids. Moreover, humic acid can readily form negatively charged colloids with iron (ferrous and ferric), aluminium and zirconium hydroxides. But, they are coagulated by the presence of calcium ions formed from calcium carbonate. In the absence of calcium, deflocculation takes place and these negatively charged oxides, hydroxides and the silicates of iron, aluminium etc. can pass into lower layers when rain falls. These may, under certain conditions, can form gels and pan formation takes place in soils.

It is well known that bivalent calcium ions are readily adsorbed on the soil surface and calcium forms more than 80% of the adsorbed base on the soil surface and that is why fertile soils are really calcium soils. When the adsorbed calcium content becomes less than 70% and calcium is replaced by sodium, we have the beginning of the alkali soils. The replacement of calcium by hydrogen ions forms acidic soils. It is well known that nitrates are more readily leached from soils than ammonium salts because most soils as a rule are negatively charged and cannot adsorb the negatively charged nitrate ions. It is interesting to note that the drainage water from cultivated fields in Rothamsted contains 0·14—0·24 parts as ammoniacal nitrogen and 15—62 parts as nitrate nitrogen per million parts of soil solution. Similarly, 98—147 parts of CaO are present per million parts of soil solution while 6—13·7 Na_2O and 1·7—4·7 parts K_2O exist per million parts of solution. The total concentration of drainage water in Rothamsted varies from 0·02 to 0·05%.

It is interesting to note that the lime content of Rothamsted heavy clay soils was approximately 5% when the classical experiments were started there in 1843 whilst the light Woburn soils contained much less lime in 1876 when the Woburn experiments were commenced. It has been reported that the present lime status in Rothamsted is 3% and in Woburn less than 0·3%.

Prof. Alfred Åslander of Stockholm in "Standard Fertilization Method of Crop Production" applies a heavy dose of farmyard manure along with calcium nitrate and superphosphate for profitable increase of crop production. There is no doubt that farmyard manure containing approximately 135 lbs. of lime per 10 tons of the manure mostly meets the lime requirement of the soil and thus Prof. Åslander is not in favour of liming and he believes that the lime consumption in Sweden is decreasing.

Organic matter and soil fertility

In 1944 the British Parliamentary and Scientific Committee published a Report on "A Scientific Policy for British Agriculture." Paragraph 1937 contains the following lines : "The highly complex part played by organic matter in the soil is, however, still only imperfectly understood. It may truly be said to constitute one of the greatest of all the ultimate problems of the use of the land all over the world ; possibly it is the greatest of these .....The efficient utilisation of urban waste products in connection with agriculture should also continue to receive close study."

Moreover, John B. Abbot, a master farmer of Vermont, U. S. A., has stated as follows : "If all the accumulated soil wisdom of a hundred generations of master farmers were boiled down to just three sentences, one of these sentences certainly would be : Provide for regular and frequent replenishment of the supply of organic matter in the soil."

The organic matter present in soils includes the living forms, roots, fungi, bacteria and small animals ; fresh remains of living matter, a more or less stable decomposition product brown or black, called "humus" and a host of intermediate products. The final decomposition products are of course water, ash, carbon dioxide and a small amount of various gases. Perhaps, the great importance of organic matter may best be realised by listing its functions in soils. The relative significance of the several items varies a great deal among different soil types. The supreme value of the addition of organic matter to soil is the fixation of atmospheric nitrogen and the preservation of the nitrogen present in or added to soil as has been established by Dhar and co-workers. The other functions have been well stated by C. E. Kellogg in 1948 as follows :

(1) "Organic matter promotes granular structure and pore space in some soils. Thus, it may aid root extension, promote entry of water into the soil, reduce soil washing, reduce soil blowing, promote aeration or exchange of gases, increase the water holding capacity and reduce baking and crust formation.

(2) It reduces evaporation, specially when used in the surface or as a mulch.

(3) It reduces the extremes of temperatures, specially high summer temperatures, when used as mulch.

(4) Humus aids in the maintenance of reaction (pH) in the soils by acting as a buffer.

(5) Organic matter aids in the retention of soluble substances including plant nutrients by holding them in living or nearly fresh forms against the forces of leaching and the base exchange properties of humus.

(6) Part of organic matter furnishes a food supply for micro-organisms and small animals in the soil including forms essential for the transformation of nitrogen compounds and for other processes important in plant nutrition.

(7) Organic matter furnishes directly and indirectly by promoting bacteria and fungi, complex organic compounds which may include both growth promoting and antibiotic substances. Very little indeed is actually known about the role of these compounds in soil productivity.

(8) Addition of organic matter, specially from normal plant of mixed types, maintains a slowly available, fairly well-balanced supply of plant nutrients including the micro-nutrients. This is very important everywhere but specially so in warm, humid countries where leaching is severe and fertilizers expensive.

Function and value of organic matter

It is now believed that plants can derive all their nutrients, except carbon, from the soil humus. Nutrients like nitrates, calcium, potassium, ammonium, phosphate etc. can be supplied by the adsorbed matter remaining on the soil and humus surface, these nutrients are in equilibrium with the same ions existing in the aqueous phase of the soil. It is well known that the adsorptive capacity of the soil humus is 4 times that of clay. It may be that the inorganic ions, like nitrate, Ca, NH_4, PO_4 etc., present in the soil, may be taken up by the wet humus derived from the organic matter, and, a part of these ions may pass into the aqueous phase to be readily adsorbed by crop roots. Moreover, it has been stated that the inorganic fertilizers produce better results in the soils containing more humus. It is certain that humus can supply almost all plant nutrients, slowly but steadily, to the growing crops. But for the supply of nitrate, specially in cold countries the humus must undergo oxidation either by better aeration or liming the material. Otherwise, ammonia will be given out which may be washed away before nitrification. A soil rich in humus has not only more moisture but it also possesses porosity and a better chance of aeration which is of vital importance for plant roots. It is no wonder, therefore, that the chemists who tackled soil problems attached great importance to humus. In tropical countries, the humus capital of the soil is very low and naturally the retention of inorganic salts in the soils, when there is heavy rain, is likely to be endangered and hence the value of artificial fertilizer cannot be pronounced in tropical countries with a heavy rainfall. It has been observed in Malayan soils that ammonium sulphate does not improve crop production whilst farmyard manure is much more profitable.

The response due to the application of ammonium sulphate in conjunction with other bulky manures, like farmyard manure, compost etc., appears to be marked. Various experiments with green manuring have been conducted at different centres in India and their results indicate that on poor land and lands of average fertility, which is indicated by yields of 1000 to 2000 lbs. of paddy per acre, the response due to the application of 3000 to 6000 lbs. of green leaves per acre is progressive. In experiments conducted at Berhampur (Orissa), a combination of green leaf with ammonium sulphate gave better yields than green leaf alone. So, a green manure crop is not completely adequate in the supply of essential elements and it should be supplemented with artificial fertilizers like ammonium sulphate, bone meals or superphosphates to get higher yields.

It has been proved beyond doubt that the major portion of paddy lands in India generally lack in organic matter which plays a great part in improving the fertility of soils and the primary requirement of paddy soil is nitrogen, mostly in the form of humus. For the tea soils Mann in 1935 stated : "There is little evidence that liberal manuring with soluble nitrogenous manures can act as a substitute for organic matter as a source of nitrogen." The green manures which have been successfully used in Ceylon, Java, Puerto Rico and Low Congo should be utilised in India where chemical fertilizers are yet unavailable in large quantities. Crop yields can be maintained or increased by adopting better rotations by making full use of animal manures and crop residues and by using lime and green manure crops. Fertilizers are wasteful on farms not possessing a good cropping system.

One thing is clear from all European and American experiments regarding artificial fertilizers and it is that when ammonium sulphate or nitrate or urea or sodium nitrate is added to crops with superphosphate and potash and usually with chalk yields of cereals, cotton and potatoes may be doubled using about 300-500

lbs. of mixed fertilizers per acre. But, in a poor country like India, this is far too costly unless the Government supplies these materials at cheap price. When the humus capital of the soil is large, as it is in European soils, the artificial fertilizers are effective, but, in soils low in humus, artificial nitrogen seems to be much less effective as observed by workers in Bengal and Malaya. The reason of this essential difference seems to be that humus, *i.e.* the mixture of protein and lignin or other organic matter possessing high adsorptive power, can adsorb the ammonium ion, the nitrate ion, phosphate ion, potash and calcium ions etc. and these adsorbed ions are liberated slowly for the benefit of crops during the whole period of their growth. This adsorption and slow liberation of the nutrient ions avoid the leaching of minerals including nitrates of soils when torrential rain falls. On the other hand, when inorganic salts are added to soils low in humus, the adsorption and retention is much less than in the humus-rich soils. Consequently, the washing away is rapid when rain falls. Under certain conditions, with inorganic fertilizers, the growing plant may have an overdose of minerals and this may be harmful.

Bromfield in his PLEASANT VALLEY has stated that near his farms, many agriculturists added inorganic fertilizers every year without increasing the humus capital and in most cases, as no lime was used, the soil became highly acidic and unfit for cultivation. But, on green manuring with the legumes, such land became fertile again. In Rothamsted experiments, no increase in the humus content has been observed with artificial fertilizers, although, they increase crop production. The root system left in the soil is not enough to fix atmospheric nitrogen and enrich the soil appreciably. As the efficiency of nitrogen fixation by organic substances in absence of phosphates is almost as low as the efficiency in the industrial Haber-Bosch process, *i.e.*, only 8 to 10% of the energy obtained by carbon oxidation may be utilised in nitrogen fixation by adding organic matter, a large quantity of organic matter has to be added in order to increase the nitrogen status of the soil permanently. By adding calcium phosphate, the efficiency markedly increases.

Another method suitable, specially for Europe, is the addition of inorganic fertilizers mixed with farmyard manure, straw, leaves, sawdust or coal etc. which can form humus and to bring the carbon-nitrogen ratio to about 11 or 12 so that the adsorbed inorganic matter can be retained by the humus formed for longer period, *i.e.* semi-permanently, in the soil. It seems that the adsorption of nutrient ions by the humus and clay and their slow liberation for the benefit of crops is one of the most important function of humus, because, plants require nourishment during the whole period of their growth.

In North Indian soils under cultivation, the humus content is approximately 1%, that is the total nitrogen is of the order of 0·05% and organic carbon 0·5%. In Rothamsted the humus is about 2·5% with a total nitrogen 0·122%. In the Royal Agricultural Farm at Uppsala, Sweden, the total nitrogen is 0·147%.

But in the U. S. A. in the cornbelt area, there are soils with 0·3% of total nitrogen. They are known as prairie soils. In Canada, Shutt has reported that there are prairie soils with 0·374% nitrogen and in one or two soils the nitrogen was 0·64% or even 1%. Most of these soils do not profit by the application of artificial fertilizers. On the other hand, Russell has reported that in the fen lands of England, the total nitrogen is of the order of 3% and these lands are rich in calcium carbonate. With the help of superphosphate, excellent potato crops can be grown. On the other hand, there are vast areas of peaty lands in cold countries, but, from the point of view fertility and increased crop

production, these lands are not suitable. They are usually acidic and hence the soil humus is not oxidised readily and available plant food is not easily obtainable. Hence, we must differentiate the acidic peaty land and the humus and mineral-rich prairie and czernogem lands of temperate countries.

In the composting of the plant materials and even of the municipal wastes, Howard and others reported that the total nitrogen content of these composts is of the order of 0·5 to 0·8%. On the other hand, by adding basic slags or rock phosphates, we have been able to obtain composts with a nitrogen content of 1·6 to 2%. In the fields in front of the Sheila Dhar Institute of Soil Science, University of Allahabad, municipal waste was dumped along with basic slags and the nitrogen content of these lands greatly increased and bumper crops were obtained. It appears, therefore, that the fertility of a land and its humus content are correlated provided the lands are rich from the calcium phosphate point of view. If the land is not rich in calcium phosphate or in the mixture of calcium phosphate and calcium carbonate but may be rich in grass and forest litters and also due to the washing away of lime and phosphates, the oxidation process is slowed down and inactive infertile peaty soils are produced whose nitrogen content may be 2 or 3%. The main difference lies in the pH and in the mineral content as well. If both calcium phosphate and calcium carbonate are present in plenty along with organic matter, rich soils (like the prairie and the czernogem soils) are produced and they behave like our phosphated composts rich in nitrogen and other plant food materials. But in cultivation a good deal of the nitrogen is lost as in Shutt's experiments due to the formation and decomposition of the unstable substance, ammonium nitrite, produced in the nitrification of nitrogenous compounds. It seems that the fen soils are not rich in calcium phosphate but rich in calcium carbonate. Organic matter mixed with calcium carbonate alone can no doubt fix atmospheric nitrogen but is not so fertile as the phosphate-rich prairie or czernogem soils.

Davies of England has reported that in wet grasslands the total nitrogen may be 12, 00 lbs. per acre, that is, of the order of 0·6%. But, very little of this nitrogen and other plant food materials are in circulation due to the lack of alkali and oxidation. It is not the total humus or the carbonaceous compounds present in a land which can help in fertility increase and crop production, but the availability is controlled by the oxidation reactions and the richness in minerals.

In preparing composts oxidation has to be facilitated for the oxidation of the extra carbohydrates, but, only in the presence of phosphates marked increase of the nitrogen status takes place and the phosphated composts are richer in plant food materials than the unphosphated ones. Similarly, if grasses, which are richer in calcium phosphate than tree materials, start decaying in presence of air, a soil richer in humus and minerals is obtained rather than a soil which contains decayed forest trees, needles and pines etc. which are poorer in calcium phosphate. Moreover, forests attract more rain than grasslands. Hence minerals from forest soils undergo greater washing away than minerals in grasslands. It appears, therefore, that in coal formation, wood organic matter is needed, *i.e.* organic matter poorer in minerals specially under anaerobic conditions and in presence of water. But czernogem and prairie soils behave like phosphated composts prepared by us and are suitable for crop production without fertilizers. Their fertility can be maintained only by adding organic matter like straw, municipal waste and farmyard manure.

The acidic and mineral-poor humus, as in peat, lignite and bituminous coal, is like the humus-rich acidic permanent grasslands of England undergoing constant leaching. In order to utilize these materials, the oxidation processes

have to be facilitated by ploughing, as emphasised by R. H. Eliot, or certainly better by ploughing in these materials with large doses of basic slags, which help in oxidation and mineralisation of plant food materials.

The nitrogen content of lignite is smaller than that in peat as shown in the following Table :

Material	Total carbon %	Total nitrogen %
Wood	49–50	1·1
Peat	56–57	2·95
Lignite	72–79	0·98
Sub-bituminous	76	1·47
Bituminous	87	1·37
Semi-bituminous	89·1	1·40
Semi-anthracite	92·1	1·20
Anthracite	94·4	0·70
Straw	31·75	0·693
Sawdust	42·3	0·21

It is well known that both lignin and lignite are brownish. It seems that the basis of lignite may be wood fibre low in nitrogen. On the other hand, peat and coal may be formed from original materials rich in nitrogen. In our experiments on nitrogen fixation we have observed that straw is an excellent fixer of nitrogen and also preserver of soil nitrogen. But coal, peat, lignite, sawdust are not so suitable as straw in the fixation of nitrogen. Similarly, mobil oil is not a good fixer of atmospheric nitrogen even in the presence of sand. When basic slag is added, the fixation becomes greater but not as good as with straw.

Agriculture began with a more or less marked displacement of the original flora by a new one which can flourish under the prevalent soil conditions. The soils are affected by drainage, additions of lime and organic matter. Calcium is by far the most important single element in the composition of the soil.

Nitrogen fixation in soils by the slow oxidation of organic matter.

It has already been emphasised that the most important function of the incorporation of organic matter in soils is the fixation of atmospheric N in the soil directly by the energy liberation in the slow oxidation of organic matter. Moreover, the organic substances also markedly retard the loss of nitrogen from soils by acting as negative catalysts in the nitrification of nitrogenous substances present in the soil or added as fertilizers and manures. We have observed that in this nitrogen fixation sunlight or artificial light is utilised actually in increasing the N status of land by incorporation of organic matter and this type of N fixation is the chief source of soil nitrogen.

It has been estimated that 1000 million tons of cereals, 800 million tons of pulses, sugars, potatoes etc. and 1600 million tons of grasses are produced in the whole world as agricultural products today. Assuming that the crop yield is 10 times the nitrogen application, the production of the world food and fodder requires approximately 360 million tons of available N per annum. It is well known that at the present moment artificial nitrogenous fertilizers provide approximately 16–18 million tons of available N and rain and snow (precipitation) provide 7–10 million tons and farmyard manure 5 million tons. Legumes have been utilised in cultivation from ancient times. Practical agriculturists found that when a legume is grown first and is followed by cereals, the cereal production is greater

than when grown in the absence of a legume. Even today in various parts of Europe and in North America legumes are grown for land fertility improvement. In fodder lands generally legumes are also grown for fodder purposes. Hellriegel and Wilfarth in 1893 experimentally proved that Rhizobia bacteria invade the host plant, that is, the leguminous crop and the bacteria work symbiotically and the bacteria grow at the root nodules and multiply from the photosynthesised carbohydrate and, in this process, nitrogen is fixed at the nodules. A. I. Virtanen of Helsinki reported that some of the amino acids produced in this N fixation pass out of nodules into the surrounding soil, which becomes more fertile.

In 1906 A. D. Hall, in his book : BOOK OF ROTHAMSTED EXPERIMENTS, reported that legumes are the suppliers of soil nitrogen and this statement was repeated by Sir John Russell in his address at Bangalore, India, in 1937. Recent studies show that approximately 2 million tons of N are fixed by legumes in the soils of the U. S. A. and 3 million tons in other parts of the world.

It appears, therefore, that the well known sources of N nutrient for world crop production including artificial fertilizers come only upto 30 million tons as against approximately 360 million tons actually utilised in the world's food and fodder production. Hence, the great reliance of the European soil scientists on legumes and the artificial nitrogeneous fertilizers is extremely unsound as the amount available, keeping in view of our present needs, is completely inadequate.

As nitrogenous fertilizers produced are not adequate to meet the world situation, we have developed an alternative method of fixing atmospheric N directly in the soil by ploughing in all types of organic substances like molasses, straw, leaves, grasses, sawdust, farmyard manure, water hyacinth (Eichhornia crassipes), lucerne, KANS (Sacchrum spontaneum), cactus, municipal waste, peat, lignite, bituminous coal etc. mixed with bonemeal, rock phosphate or Thomas (basic) slag. So far, organic matter and phosphates have been utilised separately, but, we have discovered that the two together are highly effective. A few of our laboratory experiments and field trials are recorded below :

Fixation of nitrogen in Allahabad soils.

Period of exposure (days)		Organic carbon %	Total nitrogen %	Corbon oxidised %	Nitrogen fixed lb/acre	Efficiency
		Allahabad soil + Wheat straw.				
	LIGHT					
0		0·7356	0·0492	...	...	...
90		0·5358	0·0533	0·1998	...	20·8
150		0·4762	0·0544	0·2594	...	20·6
180		0·4365	0·0553	0·2991	117·6	20·6
	DARK					
0		0·7356	0·0492	..	...	...
90		0·5866	0·0507	0·1490	...	10·6
150		0·5417	0·0511	0·1939	43·7	10·1
180		0·5241	0·0513	0·2115	...	10·2

Allahabad soil+Wheat straw+0·1% P_2O_5 as $Ca_3(PO_4)_2$

LIGHT					
0	0·7356	0·0492	...	...	...
90	0·4924	0·0566	0·2432	...	30·9
150	0·4181	0·0588	0·3175	215·2	30·3
180	0·3740	0·0602	0·3616	...	30·6
DARK					
0	0·7356	0·0492	...	...	...
90	0·5513	0·0522	0·1843	...	16·3
150	0·4851	0·0532	0·2505	90·0	16·0
180	0·4652	0·0534	0·2704	...	15·8

Fixation of nitrogen by water hyacinth

It is well known that water hyacinth, which grows abundantly in India and other warm countries, is a great menace. But we have observed that this material, containing 2·86% CaO, 1% MgO, 5·32% K_2O, 0·676% P_2O_5, 41·9% carbon and 2·39% nitrogen, when mixed with soil, can fix atmospheric nitrogen more in light than in the dark and the nitrogen fixation is increased by adding basic slag. Water hyacinth mixed with basic slag is being used as a manure in different parts of India and in Florida in rice production.

Nitrogen fixation is more accelerated by di- and tri- calcium phosphates than mono-calcium phosphate. Ferric and aluminium phosphate show a small increase of nitrogen. In all these experiments we have observed that the numbers of Azotobacter, total bacteria and fungi are much smaller in the vessel receiving light than in that kept in the dark, although, the N fixation is much greater in light than in the dark. This clearly proves the influence of light in increasing the nitrogen content of soils and their fertility by light absorption.

Temperature 25°–28°

	Period of exposure in days	Totdl carbon (%)	Total nitrogen (%)	Efficiency, *i.e.* amount of N fixed in mgms. per gm. of carbon oxidised
	Soil+water hyacinth (1·5% carbon).			
LIGHT	0	1·7305	0·1272	...
	60	1·1308	0·1424	25·3
DARK	0	1·7304	0·1272	...
	60	1·3846	0·1335	18·2
	Soil+water hyacinth (1·5% carbon) + 0·5% P_2O_5 as Tata basic slag			
LIGHT	0	1·7154	0·1244	...
	60	0.7984	0·1552	33·5
DARK	0	1·7154	0·1244	...
	60	0·9226	0·1419	22·1

Nitrogen fixation by KANS (Sacchram spontaneum)

Recently we have obtained marked N fixation by using samples of KANS with soil, specially in prsence of phosphates and light. The KANS contained 40·5% C, 0·7% N, 1% Fe_2O_3, 0·435% P_2O_5, 0·76% CaO, 0·142% MgO and 0·87% K_2O.

Soil+1·5% C as KANS (Temp. 25°)

	Period of exposure in days.	Total corbon %	Total nitrogen %	NH_3-N %	NO_3-N %	Efficiency	Azotobacter in millions per gm. of soil
LIGHT	0	4·5654	0·2576	...	...	...	1·33
	45	3·8806	0·2901	0·00580	0·00870	47·4	2·85
	90	3·4241	0·3163	0·00908	0·01300	51·8	14·20
DARK	0	4·5654	0·2576	...	...	...	1·33
	45	4·0998	0·2696	0·00366	0·00712	25·7	3·95
	90	3.9263	0·2756	0·00636	0·00879	28·1	35·40
Soil+1·5% C as KANS+0·5% P_2O_5 as Tata basic slag							
LIGHT	0	4·3553	0·2435	...	..	...	1·33
	45	3·1707	0·3104	0·0102	0·0084	56·4	2·88
	90	2·6132	0·3445	0·0137	0·0155	58·0	8·55
DARK	0	4·3553	0·2435	...	...	...	1·33
	45	3·6236	0·2691	0·0058	0·0084	34·9	4·37
	90	3·3101	0·2812	0·0067	0·0098	36·1	36·00

Nitrogen fixation by mixing soil with lucerne (Medicago sativa)

Soil+0·5% C as Lucerne (Temp. 25°)

	Period of exposure in days	Total carbon (%)	Total nitrogen (%)	Efficiency
LIGHT	0	0·901	0·0643	...
	90	0·724	0·0718	42·3
	180	0·658	0·0743	41·2
DARK	0	0·901	0·0644	...
	90	0·768	0·0673	21·7
	180	0·712	0·0682	20·1
Soil+0·5% C as Lucerne+0·25% P_2O_5 as $CaHPO_4$.				
LIGHT	0	0·902	0·0644	...
	90	0·703	0·0781	68·8
	180	0·640	0·0820	67·1
DARK	0	0·903	0·0646	...
	90	0·732	0·0706	35·0
	180	0·690	0·0718	33·7

For a number of years we have been emphasising that chalk or lime protects soil phosphates from being washed away. Consequently, under normal conditions basic slags containing lime are more durable and show residual effects better than superphosphate. This viewpoint has been supported from the classical Rothamsted experiments which started in 1843 and the Saxmundham experiments in East Suffolk from 1899. In Rothamsted the soil originally contained 5% $CaCO_3$ which may have now dropped to 3%. In these fields, the phosphate added as superphosphate has been preserved by the lime and recent experiments show that in many fields good crops are obtained without the addition of phosphates. In Saxmundham, superphosphate has been added along with artificials and compared with land receiving farmyard manure. It has been observed that the plots receiving farmyard manure annually stood out distinctly from the other fields. The soils in the dung plots are dark, friable and could be cultivated earlier. The phosphate status of these lands is higher than in those receiving superphosphate because the lime present in dung at 135 lbs. CaO per 10 tons of dung protects the phosphate from being washed away.

Increase in phosphate reserve of land vital for permanent agriculture.

Our experimental results show that a mixture of organic substances, like farmyard manure, straw, plant residues etc. and calcium phosphates, when incorporated in the soil, can build up soil fertility permanently by fixing atmospheric N and supplying available phosphate, potash, humus and trace elements and maintaining soil neutrality. Hence for a number of years we have been emphasising that the calcium phosphate reserve of soils in permanent agriculture must be increased by utilising cheap phosphate sources like basic (Thomas) slags, soft phosphate rocks etc. It is gratifying to note that this is being done in some countries as will be evident from the following lines : "Workers in Denmark and the Netherlands stress the need to maintain supply of soil phosphorus at a satisfactory level so that phosphorus deficiency does not limit crop growth . . . If phosphate fertilizers are used to maintain soil phosphorus reserves, their residual effects are of as great importance as their immediate effects. Satisfactory phosphates for "investment manuring" should be cheap and also be effective for a period of years; slow acting material may be quite suitable." (Cooke, 1956).

So far, man has utilised organic matter and phosphates separately, but, from our experiments we are convinced that the two together are very profitable for fertility increase. This conclusion is strongly supported by the following experimental results obtained in the U. S. A. (Thompson , 1957) :

Effects of manure (10 *tons/acre*) *and superphosphate* (500 *lbs. of* 0—20—0) *on yield of tomatoes in pots with different soils*

Soil type	Yield of tomatoes (gms.)/pot. Materials applied separately.	Materials applied together	Increase in yield by applying together
Woodbridge loam	8·6	29·7	21·1
Vaiden clay	14·1	27·0	13·9
Worthington loam	20·9	38·3	8·4
Vergennes clay loam	40·4	47·6	7·2
Addison clay loam	47·1	51·6	4·5
Merrimac sand loam	54·0	58·5	4·5

Moreover, when leys are dug up for re-seeding, the organic materials ploughed in are benefitted by adding phosphates because the two together can fix atmospheric N and supply plant nutrients and produce more and better grasses and legumes. This is evident in the following observations :

Treatment	lbs. gained per acre
Untreated	105
Limed and re-seeded	147
Limed, phosphated and re-seeded	155

T. W. Wright (J. of Sc. of Food and Agri., Dec. 1959, Vol. 10, p. 645—650) has recorded that the Belgian practice of putting a mixture of soil and basic slag down the planting hole in the aforestation of deep peat is utilised in the U. K. by the Forestry Commission. The best forms of phosphates are mineral phosphates and basic slag containing 16% P_2O_5.

According to H. B. Van der ford (Managing Southern Soils, 1959, p. 205), basic slag containing 8—10% P_2O_5 has been used extensively in the Southern States of the U. S. A. as a source of lime and phosphate. On page 261 he has stated : "By getting some of the necessary N from organic matter, a farmer saves on commercial fertilizers. N is the most expensive plant nutrient he buys and one of the most deficient elements in Southern Soils."

In West Germany, there is a Govt. subsidy of 20% for fertilizer consumption and its application is fairly high. Still, the production and application of farmyard manure is not adversely affected by the subsidy. It is realised that fertilizers and manures supplement each other. Agricultural engineers are simplifying and improving farmyard manure production in Germany.

In France, the use of basic slag, which is cheap, is increasing and taking the place of superphosphate. Natural permanent grass receives little fertilizer since grazing is thought to be sufficient to feed the soil. This leads to poor yield due to deficiency of P_2O_5. The application of basic slag or ground phosphates improves and doubles the yield by liberating available N and phosphate.

Prof. F. Scheffer of Gottingen, in his paper on 'The effective Use of Fertilizers Including Lime' (O. E. E. C. publication, Paris, April 1959, page 69), has stated that "An intensification of fertilisation on light soils, as required by fallow crops, can only be carried out in association with heavy humus and phosphate fertilization. The phosphoric acid not only serves as a plant nutrient but also, in association with humus, serves to increase the buffer reaction and also promotes as well an improvement of the chemical and biological properties of the soil and, consequently, an increase of soil fertility." "For tropical soils, sufficient humus is of the utmost importance as only thereby the basic condition of successful fertilizer application is created. In tropical soils, the clay materials with a high buffer effect are very often lacking. In addition the regulative effect of phosphoric acid is prevented by the presence of large quantities of sesquioxides."

According to Prof. Steenbjerg of Denmark, basic slags and rock phosphates and bonemeal respond well when applied to humus soils of low pH value.

Formation of fertile soil from earth's crust.

We have carried on a large number of experiments in the slow oxidation of energy materials when mixed with soils or chemical surfaces like oxides of iron, nickel, aluminium, titanium, silicon etc. These surfaces do not contain any

nitrogenous material. We have observed that the efficiency of nitrogen fixation, *i.e.*, the amount of nitrogen fixed per gram of carbon oxidised, is greater in the oxide surfaces than in our soils containing 0·04—0·05% total nitrogen. Moreover, by increasing the total N in soils by the incorporation of nitrogenous compounds and mixing the nitrogen-rich soil with organic materials, there is nitrogen fixation in the slow oxidation of the energy materials. But the efficiency of N fixation falls off as the initial N content of the system increases. The higher value of efficiency in N fixation obtained with oxide surfaces as compared with that obtained in soils is due to the fact that the phenomenon of N fixation and N loss go on simultaneously. The fixation process is opposed by the loss due to nitrification. The unstable explosive substance, ammonium nitrite, which is formed in the process of oxidation of nitrogenous compounds involved in the nitrification of proteins, amino acids and ammonium salts formed by fixation of atmospheric N or originally present in the system, undergoes rapid decomposition according to the equation : $NH_4NO_2 = N_2 + 2H_2O + 718$ K. cals. This is the main chemical change involved in the loss of nitrogen always observed in the nitrification of nitrogenous compounds. In soils there is always a certain amount of combined nitrogen *i.e.* to the extent of 0·05% in tropical soils. Hence, the loss of nitrogen is more marked in soils than on oxide surfaces containing no nitrogen, and, the process of nitrogen fixation on oxide surfaces becomes more productive than in soil systems because the fixation process and the nitrogen loss go on simultaneously opposing each other ; and when the nitrogen of the system increases, the loss may compensate the amount of nitrogen fixed from the energy obtained from the slow oxidation of energy materials. These observations are of fundamental importance in explaining the evolution of fertile soils from the earth's crust obtained from the parent rocks of geological ages. The earth's crust does not contain any appreciable organic matter, but may contain small amounts of nitrate or ammonium salts from rain water or snow or dust. These nitrogenous compounds under the inflnence of solar light and moisture and seeds form the first set of vegetation or plant life or alga on the earth's crust the nitrogen need of which is met from the inorganic nitrogen present in the earth's crust in small amount. The energy materials photosynthesised containing cellulose, fat, soluble carbohydrates or other energy materials formed in photosynthesis, undergo slow oxidation and liberate energy causing N fixation which is markedly aided by light absorption and calcium phosphates present in the system. By the fixation of atmospheric N, the nitrogen store increases. This in turn leads to a more abundant growth of vegetation and this process goes on by which the carbon and nitrogen status of the system is improved, leading to the formation of a fertile soil. This N fixation, which in the beginning is a non-biological surface reaction aided by light absorption, as the original earth's crust is poor in nitrogenous compounds, is more efficient in the beginning, but, with the storing up of nitrogen, the efficiency falls off and thus the nitrogen and carbon status of the system reaches a maximum limit depending upon the climatic conditions.

But, the maximum N increase can be improved by the incorporation of calcium phosphates which stabilise the nitrogenous compounds and avoid the loss of nitrogen.

Organic matter in the soil may be created by the growth of alga also. It is believed to be valuable in many soils, but, on newly formed soils, it is of the greatest importance. The carbon of the algae, when decaying, is slowly oxidised and the energy liberated leads to the fixation of atmospheric nitrogen. Our observations show that the growth of algae is slow and hence the amount of carbonaceous compounds added by algal growth is not large. N fixation by algal

growth and decay is smaller than by the addition of carbonaceous materials like farmyard manure, leaves, grasses etc. The greater the carbonaceous matter added to the soil, the greater the oxidation and greater the fixation of nitrogen, as has been recorded in this paper.

Till the beginning of the present century, cattle dung or farmyard manure, alone or mixed with chalk, used to be the chief fertilising manure in crop production in Europe. It was believed that dung in its decomposition supplies nitrogenous compounds, potash, phosphate, lime, magnesia etc., present in the dung, to the crops growing on land and the chalk prevents the acidification of the land by washing. From our experiments we have established that dung or farmyard manure with C/N ratio of 20 or 22 not only supplies the plant nutrients contained therein, but, can fix appreciable amounts of nitrogen and make the soil fertile and in this process phosphate rocks, basic slags, bones etc. are of supreme importance and are better than calcium carbonate. Moreover, all organic substances leave a residual effect in the soil because of the humus formation and fixation of atmospheric nitrogen. It is clear that whenever a residual effect of a manure has been observed, *e.g.* molasses, straw, hay, farmyard manure, grasses, it is chiefly due to N fixation in soil and little residual effect is observed with legumes with a C/N ratio much smaller than that of farmyard manure or straw.

Phosphates helpful in the formation of Nitre beds.

In a number of publications, Dhar has advanced a theory explaining the formation of natural nitre beds in Chile and other parts of the world based on the phenomenon of N fixation aided by sunlight. It has been reported that phosphates exist in the overlying rocks near deposits of the Chile salt petre. From our experiments we have observed that when calcium and other phosphates are mixed with all types of organic matter undergoing slow oxidation, there is marked fixation of atmospheric N and formation of proteins and amino acids and salts of ammonia. This fixation of N by the slow oxidation of organic matter is much greater in presence of light than in its absence, and, actually, light is utilized in producing more nitrogenous compounds. Moreover, in presence of calcium and other phosphates, the fixation of nitrogen is much accentuated.

Hence, all types of organic substances like sea weeds, planktons when mixed with guano or bird deposits or bones of fishes or animals rich in calcium phosphate, fix atmospheric N copiously, specially in the presence of sunlight in areas like Chile, Peru etc. These nitrogenous compounds in course of time can undergo nitrification more in light than in the dark and can be converted into nitrates of sodium, potassium, calcium, magnesium etc.

We have observed that when potassium salts sodium salts or soluble calcium or magnesium salts are mixed with nitrogenous substances undergoing nitrification, the formation and decomposition of the unstable and explosive substance, ammonium nitrite, which is always produced in the nitrification of nitrogenous compounds, is decreased due to the formation of nitrites of the alkali and alkaline earth metals. Consequently, the formation of nitre beds may be due to the photochemical, catalytic and bacterial nitrification of the nitrogenous compounds obtained from weeds, planktons, animal bodies and those fixed in the slow oxidation of organic substances with C/N ratios greater than 10 aided by calcium phosphates derived from sea animals, fishes and dung of the birds.

It is quite possible that under certain conditions, the soluble nitrates thus produced may be separated from the calcium phosphate by washing down the highlands and accumulated by the evaporation of water in the valleys. That sea water and sea weeds and materials present in the sea bed play an important role

in nitre bed formation is clear from the following composition of an average sample of caliche which contains many chemicals present in sea water and beds : Sodium nitrate 8 25%, potassium nitrate 2–3%, sodium chloride 8–25% sodium sulphate 2–12%, calcium sulphate 2–6% magnesium sulphate 0·3% sodium biborate 1–3%, sodium iodate 0·05–0·1%, sodium perchlorate 0·1–0·5% and insoluble matter 23 70%.

Greater efficiency of nitrogen in crop production in countries using small amounts of commercial fertilizers.

In the following Table the total agricultural areas, total nitrogenous fertilizers used (1956–57), amounts of N in Kg. applied per hectare of land under cultivation and cereal productions in various countries are recorded :

Country	Total agricultural area in 1000 hectares	Nitrogenous fertilizers used (million tons)	Commercial N per hectare in Kg. applied	Cereal production (million tons)	$\frac{\text{Cereal}}{\text{N}}$
U. S. S. R.	486,400	1·5	3·3	160	214
U. S. A.	444,236	2·0	4·8	140	140
China	287,350	0·12	0·4	100	168
India	169,496	0·154	1·0	72	934
Turkey	53,818	0·006	0·12	11·5	3800
France	33,668	0·403	13·0	19·0	94
Spain	29,549	0·169	6·1	7·8	92
Pakistan	24,404	0·031	1·3	18·3	1202
Italy	20,936	0·268	13·2	13·6	102
Poland	20,404	0 153	8·0	12·2	158
U. K.	19,364	0·311	17·3	8·3	54
Yugoslavia	15,933	0·067	4·2	5·9	176
West Germany	14,416	0·527	39·5	12·0	50
Greece	8,703	0·055	6·3	1·95	72
Thailand	7,793	0·C03	0·4	8·3	5600
Philippines	7,588	0·033	4·3	4·26	280
Hungary	7,266	0·025	3·4	5·3	424
Czechoslovakia	7,377	0·021	2·8	5·5	520
East Germany	6,474	0·218	36·4	5·4	48
Japan	6,404	0·587	92·0	17·1	58
Portugal	4,868	0·047	9·5	1·5	64
Ireland	4,726	0·0145	3·0	1·3	176
Bulgaria	4,537	0·081	18·0	3·45	84
Sweden	4,436	0·09	20·0	3·0	66
Austria	4,088	0·037	9·0	1·91	100
Denmark	3,117	0·0978	31·3	3·81	77
Finland	2,869	0·044	15·3	1·27	56
Switzerland	2,708	0·011	4·2	0·44	80
Egypt	2,618	0·123	46·5	5·5	90
Netherlands	2,305	0·189	86·4	1·57	17
Belgium	1,730	0·087	55·1	1·58	38
Ceylon	1,523	0·0212	15·0	0·54	49
Norway	1,032	0·045	48·6	0·54	24
Taiwan	936	0·084	96·8	2·27	54
Luxembourg	141	0·0037	28·3	0·111	60

If we assume that only 50% of the nitrogenous fertilizers applied in the above countries are used in cereal production and divide the amounts of cereals produced by the quantities of N fertilizers utilized for growing the cereals, we obtain some interesting figures recorded in the last column of the above Table. They show that in countries where larger amounts of N fertilizers are applied per unit area, small values are obtained as the ratio of Cereal : N as recorded in the last column of the above Table. There ratios are recorded in increasing order in various countries : Netherlands (17), Norway (24), Belgium (38), East Germany (48), Ceylon (49), West Germany (50), U. K. Taiwan (54), Finland (56), Japan (58), Luxembourg (60), Portugal (64), Sweden (66), Greece (72), Denmark (77), Switzerland (80), Bulgaria (84), Egypt (90), Spain (92), France (94), Austria (100), Italy (102), U.S.A. (140), Poland (158), China (168), Ireland, and Yugoslavia (176), U.S.S.R. (214), Philippines (280), Hungary (424) Czechoslovakia (520), India (934), Pakistan (1202), Turkey (3800) and Thailand (5600). On the other hand, the decreasing amount of commercial nitrogen used per hectare of land in Kg. under cultivation in various countries are as follows: Taiwan (96·8), Japan (92), Netherlands (86·4), Belgium (55·1), Norway (48·6), Egypt (46·5), West Germany (39·5) East Germany (36·4) Denmark (31·3), Luxembourg (28·3), Sweden (20), Bulgaria (18), U. K. (17·3), Finland (15·3), Ceylon (15), Italy (13·2), France (13), Portugal (9·5), Austria (9), Poland (8), Greece (6·3), Spain (6·1), U. S. A. (4·8), Philippines (4·3), Yugoslavia and Switzerland (4·2), Hungary (3·4), U. S. S. R. (3·3), Ireland (3), Czechoslovakia (2·8), Pakistan (1·3), India (1), China and Thailand (0 4) and Turkey (0·12).

From the foregoing observations it appears that in countries not using larger doses of commercial fertilizers, the nitrogen response to cereals is very marked and that the law of diminishing return, which is often neglected in modern agriculture by applying heavy doses of commercial fertilizers, is in actual operation in countries like Netherlands, Belgium, Norway etc. But in countries like Japan, China, Taiwan where a lot of composts, plant and animal wastes are utilized along with commercial fertilizers, better crop yields per unit of N applied are still obtained. It is of interest to record here that several experiment stations in the U. S. A. have found that yields of wheat and corn are increased by producing greater amounts of organic matter through rotations. If all crop refuse is used and if legumes are grown in rotation, the organic matter level is fairly well maintained. But in drier areas legumes have to be replaced by grasses for building up of the organic matter.

In the O. E. E. C. publication THE EFFECTIVE USE OF FERTILIZERS INCLUDING LIME, April 1957, page 87, Prof. K. A. Bondorff, Director, State Laboratory, Lyngby, Denmark, has reported : "I will only say that the consumption of fertilizers could profitably be increased by 60%, thereby causing an increase in yields of 4%. I think that we can easily agree that there must be such a thing as a maximum profitable consumption. But how to calculate this quantity? I should like to stress that the answer is a very important one. It is important to the single farmer, who, of course, want to benefit as much as possible from the use of fertilizers. It is important to the national economists and to the politicians who want to estimate to what extent their country can supply itself with food. And last but not least, it is important to the manufacturers of fertilizers wanting to know the maximum quantity they can hope to sell off. The question is as difficult to answer as the answer is important. But I think the answer will be important still in another way. The answer might be useful to people, including many politicians, who know too little about agriculture. When it is emphasised that agriculture in future will have increasing difficulties in meeting the demand of

food, these people point to the role fertilizers have played and believe that by increasng the use of fertilizers, every demand can be met. Looking backwards, this point of view can be understood. But looking forward, the picture is quite different. The possibilities of an increased use of fertilizers are, in my opinion, often overestimated, the law of diminishing return too often neglected."

On page 84 and 85 Prof. Bondorff stated as follows : "The phosphoric acid condition and the potash condition of the soil has to be in order, *i.e.* sufficient quantities of these two nutrients have to be available in the soil for plants in order that they can fully utilise the expensive nitrogenous fertilizer and the water etc. .... In other words, it does not pay to have the yield determined by the relatively cheap phosphoric acid and potash nutrients. Then one should give as much phosphoric acid and potash as will be sufficient for the plants."

Plant food in U. S. A. soils.

In the U. S. A. which is highly industrialised and whose agriculture is considerably mechanised, only 10% of the population work in the farms, 7·5 million tons of nitrogen are removed in crops and 1·5 million tons of N are applied as artificial fertilizers to the 510 million acres of land under crops and pasture. It is estimated that 4·5 million tons of potash are taken up by crops and only 1·5 are replenished by fertilizers. On the other hand, the phosphate intake of 2·1 million tons by crops is balanced by the application of phosphate fertilizers. The distribution of fertilizers cropwise is recorded below as the percentage of the total plant food supplied by chemical fertilizers in the U. S. A. :

Crops	N	P_2O_5	K_2O	Total acreage in million acres
Corn	30	95	70	83
Small grains	12	187	81	150
Cotton	62	74	29	18·7
Vegetables, potatoes and fruits	96	173	94	17·0
Tobacco	95	1480	100	1·6
Hay and pasture	3	44	15	280
	17	99	33	510·3

It appears, therefore, that paying crops like cotton, tobacco, vegetables and fruits are copiously fertilized. To corn and small grain crops, phosphate and potash are adequate but nitrogen is low. In hay and pasture lands, the application is extremely low. From the above figure it is clear that 6 million tons of N and 3 million tons of potash are in deficit each year in the agriculture of the U. S. A. There is no doubt that a certain amount of plant food is supplied by precipitation. Moreover, the U. S. A is legume-minded and it has been estimated that 2 million tons of N are fixed in the agricultural lands of the U. S. A. by legumes.

Regarding the amount of plant nutrients supplied by barnyard manure, the position is uncertain. Salter and Schollenberger estimated an annual production of manure in the U. S. A. @ 1·02 ton per acre of land in crops and pasture. If this estimate is correct, the manure supplies 2·5 million tons of N, 1·2 million tons of phosphate and 2·2 million tons of potash.

However, C. E. Miller has stated that dung supplied 6·57 million tons of N in 1956–57, 1·03 million tons of P and 5·35 million tons of K. J. G. Lipman and A. B. Conybeare have stated the plant nutrient position as follows :

Annual Balance of Plant Nutrients in the U. S. A.

	Nitrogen (tons)	Phosphorus (tons)	Potassium (tons)	Calcium (tons)	Magnesium (tons)	Sulphur (tons)
Losses : (harvested crops, grazing, erosion, leaching).	22,899,046	4,221,302	50,108,560	68,185,730	24,557,881	12,043,911
Additions : (fertilizer & liming materials, manure and bedding, rainfall, irrigation waters, seeds nitrogen fixed).	16,253,862	1,447,835	5,151,076	12,561,673	4,040,813	9,029,690
Nett annual loss.	6,645,184	2,773,467	44,957,484	55,624,057	20,517,068	3,014,221

From the foregoing considerations it appears that there is a loss of something like 6 million tons of nitrogen and huge losses of potassium, calcium, magnesium and sulphur every year from the U. S. A. soils. In a recent article, W. B. Bollen has also come to the conclusion that the plant food materials and fertility in the soils of the U. S. A. are decreasing although the use of commercial fertilizers, specially N, has increased markedly in the last 10 years. The following lines of Bollen are of great interest :

> "Producing more and more from less and less acreage is a demand characteristic of our economy. The population is rapidly increasing and exerting on available food supplies a pressure that poses a grave problem in the coming decade. Not only have we reached the limits of land available for farming but agricultural space is shrinking at the rate of a million acres annually due to expansion of our cities, building of industrial sites and construction of highways. We should regard our soil with profound concern. Harvested crops remove plant food and the fertility of cropped soils is declining. Despite of the use of fertilizers and crop residues, how long can improved farm practices and the pressure for increased crop yields continue without deleteriously affecting beneficial soil organisms, without developing some hidden hunger or depleting some aspect of soil fertility that must be restored by means now unknown ? Future research will provide the answer and it is likely that some phase of soil microbiology will assist in finding it."

Loss of humus from the soils of U. S. A.

J. H. Stallings of the U. S. A. (Soils Use and Improvement, 1957) has recorded that 35 million acres of cultivated land of the U. S. A. cannot grow food and have been abandoned as worthless and 1½ million acres are being worn out every year. Moreover, in the most productive lands in the midwest and great plains, much of the organic matter has been lost and the natural fertility is going down. There is no doubt that the organic matter content of a soil is a fair index of its productive power and durability. It has been frequently observed in different countries that the graph of the yield from increasing doses of nitrogen shows a higher maximum when straw is added than in its absence.

The following observations on corn cultivation and soil erosion at the Ohio Agricultural Experiment Station at Wooster, Ohio, are of interest in this connection :

Crop every year	Fertilizer treatment	Soil loss in inches : 1894–1935	% of organic matter remaining in soil in 1935	Average yield in bushels 1894-1935.	Average yield in bushels 1931-1935
Corn	None	10·3	37	26·3	6·5
Corn	Complete (500 lbs. of 10–5-10 per acre).	11·1	35	44·4	28·9
Corn	Manure at 5 tons per acre.	9·5	53	43·1	30·0

The manure is effective in decreasing erosion and maintaining the humus.

Soil productivity depends on structure, aggregation, texture, micro-organic life and all these are created by organic matter. The humus content of the Corn Belt land of the U. S. A. is declining due to inadequate replacement of organic matter and the yield is decreasing as seen in the above Table. In various parts of the world, either the organic matter has been returned to the land in insufficient amounts or humus oxidation has been promoted by too frequent cultivation and application of heavy doses of the nitrogenous fertilizers. There is nothing more important than a good sod of grasses and legumes to hold the soil in place.

In this connection it is of interest to record the following statements from an article on "Overall Economic Considerations In Fertilizer Use" by E. L. Baum and E. O. Heady, 1957, p. 125 : "Even if the total increase in crop production in the U. S. A. by applying artificial fertilizers is 25%, it is remarkable that this portion of a wealthy nation's food product comes from the resource—fertilizer. The social significance of fertilizer in the nation's producing plant and economic growth processes, fertilizer is becoming an extremely important substitute for labour, land and other particular forms of capital. Thus fertilizer is one of the potential elements of further economic growth in the U. S. A."

Dr. Alf Åslander in his publication on "Nutritional Requirements of Crop Plants in the HANDBUCH DER PFLANZENPHYSIOLOGIE has recorded as below :

> "Dhar, on the basis of investigations and observations throughout a lifetime, makes the following statements : Practical farmers in many countries prefer to grow good quality crops by the uptake of nitrogen slowly but steadily supplied by the soil humus. Dung or straw is a lasting manure and builds up what farmers call 'high conditions' of a soil. The repeated application of municipal waste products increased the nitrogen content of an Allahabad field from 0·04 to 0·25% and bumper crops were obtained. It appears that crops of which the potash requirement is more pronounced than their available nitrogen need are likely to respond well to organic manures. Crop production on a mixture of farm manure and artificials is better than with the use of artificials alone. Land under grass becomes more fertile because grass adds organic matter to soil and improves the physical properties. In France, too, some results supporting the organic view have recently been reported."

Farmers in Europe have observed that it is not as a rule possible to obtain high yields indefinitely without organic manures as the residues left in the soil after the harvest are not adequate to maintain the optimum rate of humus.

Nitrogen loss—a general phenomenon in ammonia oxidation.

Practical agriculturists have reported a marked loss of nitrogen in cultivation. Sir John Russell has recorded a loss of 60% of N added in the form of farmyard manure @ 200 lbs. of N per acre per year in the Rothamsted fields. Dhar has recently calculated and found a similar loss from the field trials in Rothamsted using ammonium sulphate or sodium nitrate. Shutt in Canada and Lipman, Blair and others in the U. S. A. reported a loss of 68 to 100 lbs. of N per acre per year. In his book SOIL CONDITIONS AND PLANT GROWTH, 1937, Russell stated that in bacterial nitrification of nitrogenous compounds, no loss of nitrogen takes place. But, recently, Dhar and Pant reported losses of 60% of N in the bacterial nitrification of different nitrogenous compounds.

For a number of years we have been carrying on extensive research work on the slow oxidation of ammonium salts and other nitrogenous compounds by air in presence of soil etc. We have observed that with ammonium sulphate and other ammonium salts, there is a loss of about 60% of N more in light than in the dark. We have ascribed this loss in the nitrification of nitrogenous compounds in soil at ordinary temperature to the formation and decomposition of the unstable substance, ammonium nitrite.

On the other hand, in the industrial preparation of nitric acid from ammonia, Kuhlmann in 1839, observed that platinum was an excellent catalyst. Ostwald pushed this research further and reported that it was advisable to pass a mixture of air and ammonia as rapidly as possible over the catalyst, and that for each catalyst, there was a definite velocity at which a maximum yield was obtained. With platinum, the yield of nitric acid from ammonia is 95% and this is the present industrial method. Germans have used other catalysts, but, the yield of nitric acid is smaller than with platinum.

Ammonia burns in air under the influence of catalysts and forms, in the 1st instance, a white fog of nitrite and nitrate. At 300°, reddish brown vapours appear and with increasing temperature, more and more free nitrogen and steam are produced. It has been postulated that the following reactions take place between ammonia and oxygen :

1. $4NH_3+5O_2=4NO+6H_2O+215{\cdot}6$ cal.
2. $2NH_3+3O_2=2HNO_3+2H_2O+153{\cdot}7$ cal.
3. $NH_3+2O_2=HNO_3+H_2O+80{\cdot}9$ cal.
4. $4NH_3+3O_2=2N_2+6H_2O+302$ cal.
5. $4NH_3+7O_2=4NO_2+6H_2O+269{\cdot}5$ cal.
6. $4NH_3+6NO=5N_2+6H_2O+431{\cdot}6$ cal.

According to Neumann and Rose, 90% of oxidation products consists of nitrous acid when ammonia burns in air. In presence of oxygen 70 to 80% of nitric acid and 20 to 30% of nitrous acid are formed. From the very beginning of the oxidation reaction (4), liberation of free nitrogen takes place along with other reactions as stated above. The extent to which it occurs increases with the rise of temperature. Reaction (4) also depends on the amounts of catalysts used and on the velocity of gaseous mixture. Reaction (6) is very important as it already takes place at a temperature at which the formation of nitric oxide commences. Reaction ($NH_4NO_2=N_2+2H_2O+718$ cal.) also gives rise to the formation of nitrogen gas. All the above reactions are exothermic and cause a rapid rise of temperature as soon as one or the other of them starts.

Ostwald attempted to increase the yield of nitric acid by the catalytic oxidation of ammonia by increasing the flow of gaseous mixture. The observations of Neumann show conclusively that the maximum yield of nitric acid by the catalytic oxidation of ammonia is obtained at a temperature of about 500°. At lower and higher temperature, more gaseous nitrogen is produced. With other catalysts the production of nitrogen gas is more pronounced. Hence, in industrial operations, even today, platinum is pratically the only catalyst used.

The real factor in increasing the yield of nitric acid is to convert the whole of the ammonia into its oxidised products quickly, because, when ammonia is present, it reacts rapidly with the oxidised products—nitrous acid, nitrogen dioxide—and very likely with nitric acid at a high temperature.

When ammonium salts, urea, uric acid, protein, oil-cakes etc. are added to soils, the 1st product formed is ammonia from protein, which, in its turn, is converted into oxidised products like nitrite and nitrate. It is clear, therefore, that under these conditions and at ordinary temperature, the whole of the ammonia cannot be converted into oxidised products readily and hence ammonium ion, and occasionally free ammonia, have to co-exist with nitrite ion or nitrous acid, nitrate ion and/or nitric acid, and, thus, decomposition takes place with evolution of nitrogen gas. Evolution of nitrogen gas from nitrogenous compounds in soil or in surface has to be more pronounced than in the catalytic oxidation as in the industrial process, because, oxidation of ammonia at high temperatures in the catalytic process has a larger velocity than that at ordinary temperatures in soils or in presence of sand surfaces.

There is no doubt that the loss of nitrogenous matter in soil is slowed down by addition of organic matter and thus crops can extract ammonium ion and

nitrate under such conditions for a larger period and, hence, under ideal conditions, the recovery of nitrogen, which is believed to be 50% or less, can be improved by mixing ammonium salts with organic matter. But this loss can never be stopped, because, the negative catalytic effect of carbohydrates and other substances decreases with the decrease in the concentration of such carbohydrates which are liable to be oxidised on cultivation.

Farmyard manure or straw mixed with artificials produces more crop.

On the other hand, if the nitrogenous matter is associated with minerals like sodium salts, potassium salts, calcium salts, the process of ammonification and nitrification is likely to produce less nitrogen gas because a part of the ammonium nitrate formed is likely to be converted into ammonium sulphate or chloride and alkali nitrites which are more stable. Our recent experiments show that addition of potassium chloride to ammonium salts or urea appreciably decreases the loss of nitrogen by nitrification.

The following data recently obtained at Rothamsted show clearly that both straw and cowdung, when added to artificials, produce beneficial results:

	Yield of potatoes in tons per acre	
	No N, no K.	*N no K.*
No farmyard manure	4·0	4·4
With ,, ,,	9·3	11·1
Response to farmyard manure	5·3	6·7

It is evident from the above data that the yield of potatoes should have been 9·7 tons (9·3 tons due to farmyard manure and 0·4 ton due to artificial nitrogen), but, the total yield is 11·1 tons. These results show that addition of farmyard manure to artificial nitrogen produces an enhanced effect of the added mineral nitrogen.

Crowther and Yates (Emp. J. Expt. Agrl., 1941, **9**, 77) have reported as follows:

"The response to phosphate and potash is substantially reduced when dung is applied; but crops are equally responsive to inorganic nitrogen on dunged and undunged land. With potatoes there are positive interactions between nitrogen and phosphate and between phosphate and potash, but, there is little interaction between nitrogen and potash."

One thing is perfectly clear from these results obtained with different manures that in presence of dung, response to potash or phosphate is half or less than that in the absence of dung, whilst with nitrogen, the position is entirely different and response to unit weight of nitrogen does not fall off as the total dressing is increased by addition of 28 lbs. of nitrogen as ammonium sulphate. The curve of response of artificial nitrogen in presence of dung is much steeper than with potash or phosphate in presence of dung. This conclusion can only be explained satisfactorily from the viewpoint that organic matter present in farmyard manure enhances the value of artificial nitrogen.

Moreover, the following experiments on potatoes and other crops carried out at Rothamsted for a number of years in which a given dressing of straw and nitrogen was ploughed into the soil, are compared with the same quantity of straw rotted with the same quantity of nitrogen in a compost heap and then

applied to land. The ploughed-in straw has always a better yield than the compost as shown belew:

	12 *years* (1934–1945).			
	Year of applying straw.		*Year after application.*	
	Compost	*Straw ploughed-in*	*Compost*	*Straw ploughed-in*
Potatoes (tons per acre)	7·86	9·40	7·40	7·97
Sugarbeet, sugar (cwt/acre) ..	37·00	41·2	36·4	38·2
Barley, grain (,, ,,) ..	27·7	31·2	26·5	27·9

Lady Eve Balfour in Suffolk, England, obtained 30·5 cwt. of barley grains by ploughing in straw mixed with 100 lbs. of P_2O_5 as basic slag as against 20·4 cwt. by the application of 112 lbs. of nitrogen as $(NH_4)_2 SO_4$ and 14·20 cwt. in the control plot.

In recent years we have conducted a very large number of field trials in normal and alkaline lands of Uttar Pradesh, Rajasthan and West Bengal and obtained greater yields of paddy and wheat by the direct ploughing in of straw, leaves, municipal waste etc. mixed with basic slag (Indian and European) than those obtained by the application of composts from the organic matter and slags.

Sunlight increases soil nitrogen content.

Moreover, since 1951 in our publications, the greater nitrogen contents of grasslands than in forest or timber lands have been explained from the viewpoint that in grasslands there is more calcium phosphate and they receive more sunshine than the forest lands. Recently, we have compared the nitrogen status of grasslands and those of neighbouring lands under bushes and shrubs and we have always observed greater amounts of nitrogen in the grasslands than in lands receiving lesser sunshine.

Hans Jenny and S. P. Raychaudhuri have reported that comparison of Indian with American soils, particularly those of California, Texas, Atlantic Coast showed an unquestionable superiority of the former over the latter when sites having equal mean annual temperatures were compared. But, the Indian soils had much lower nitrogen and carbon contents than the tropical soils of the Central and South America.

Moreover, the average nitrogen content of soils of Ootacamund and Kodaikanal which are hill stations in the South of India near the equator, is 0·335% and 0·332% respectively, whilst the North Indian hill station of Simla has 0·241% N and in Mussoorie, it is 0·266% N. Similarly, Ambala and Aligarh, lying in the Northern Indian plains, show a nitrogen status of 0·036% N and 0·044% N, whilst Madras and Madura in the South near the equator have 0·054% and 0·062% N respectively. The rainfall and temperature in all these stations are about the same.

These observations showing greater nitrogen status of land near the equator support the photochemical viewpoint of nitrogen fixation. Undoubtedly, world soil nitrogen is created by the fixation of atmospheric nitrogen in the slow oxidation of organic matter aided by sunlight absorption and phosphates.

At the present moment in the U. K., there is a great movement to plough up grasslands in order to mobilise the nutrients present in the humus of the grasslands. Davies has reported that approximately 6 tons of total nitrogen are

present per acre in the British grasslands. There is no doubt that if these lands are ploughed up and phosphated with basic (Thomas) slags or rock phosphates, all the plant nutrients should be available to the succeeding crop. In order to avoid the trouble and expense of ploughing up the grasslands, the farmers are advised to apply large doses of artificial fertilizers. But, as has already been explained, this procedure leads to marked loss of humus and soil fertility in the long run.

In the U. S. A., under the leadership of G. Scarseth, heavy doses of N, P, K are applied for producing big yields of corn, but, before his death, Scarseth realised that without ploughing in, after removal of grains, all the corn stalks, stubbles, roots etc. amounting to 3 tons per acre of organic matter along with fertilizers, the corn production decreases. These results of Scarseth are in strong support of our studies emphasised in this communication.

In Germany, large amounts of artificial nitrogenous fertilizers have been applied for producing grasses abundantly, but without legumes. This is detrimental to soil humus and leads to soil deterioration. Most soils in North-West Europe supporting grasses are certainly rich in total nitrogen created by the fixation of atmospheric nitrogen but their humus is inactive and unable to supply the required amount of plant nutrients as there is small oxidation of the organic matter, specially under acidic conditions prevailing in most grasslands.

Some interesting results have been obtained on the carbon-nitrogen status of African soils. Undisturbed forest soils in Ashanti, Ghana and Kwadaso contain 0·126 to 0·246% total nitrogen and 1·72 to 3·05% organic carbon and the nitrate and the ammoniacal nitrogen are in fair amounts. In Nigeria, where the rainfall varies from 50 to 130 inches, surface forest soils contain 0·147 to 0·257% total nitrogen. Similarly, in Liberia, Ivory Coast, Angola, the total nitrogen varies from 0·13 to 0·33%. In Belgian Congo, Tanganyika, the high values of 0·625% have been reported.

The foregoing results show clearly that the carbon-nitrogen content of African soils is much higher than that of those in India. The reason seems to be the same as recorded in explaining the higher carbon and nitrogen contents of soils round about Madras than in the Panjab; in other words, the carbon-nitrogen content depends a good deal on sunlight absorption. According to C. E. Kellog, forest areas in Belgian Congo do not suffer from N deficiency.

Birch has reported that in East Africa the oxidation of soil humus and the production of nitrate is slow in wet soils but becomes rapid when dry soil is wetted. This is certainly due to the lack of oxygen in wet condition, but along with water, oxygen is incorporated when dry soils are wetted.

Phosphorus in African soils.

African cultivators, after several years of cultivation, allow the land to revert to forest land. In this process, phosphorus accumulates, being returned to the soil by the decay of organic matter. According to Nye, forest soils contain more total phosphorus and more phosphorus in each of the fractions than in the Savanna soils. The organic phosphorus content is closely related to the organic carbon. The carbon : phosphorus ratio is 333 in the forest and 247 in the Savanna soils. These values are considerably above the world average. Moreover, the nitrogen : phosphorus ratio is 21·6 in the forest and 19·5 in the Savanna soils. These values also are above the world average, but, the total phosphorus is low from the world standpoint.

For Nigeria, Vine (1953) emphasised the supply of phosphorus in the forest area which is richer than in the Savanna, there being no spectacular response by

field crops to superphosphate. A rapid loss of fertility follows in soils readily leached of phosphate.

In the Ivory Coast, Berlier *et al* (1956) showed that forest soil in the vicinity of Duboucosrous experiencing 60–80 inches rain, contains a high value of acid-soluble phosphorus, at $2\frac{1}{2}$ inches, P_2O_5 being 0·215–0·253%, and at 40 inches 0·200-0·273%. For secondary Savanna in the vicinity, the values are roughly equivalent. In the Belgian Congo, Kellog and Davol (1949) considered the total phosphorus to be generally low but comparable with that in the United States reddish-yellow podsolic soils.

A problem in the annual cropping of forest soils is the loss of phosphorus by leaching from the exposed soil experiencing heavy rain, the phosphorus requirement of the cereal and other annual crops being moderate to high. Where shifting cultivation does not utilise the same soil for upwards of 8 to 12 years, the loss in phosphorus is replenished by the secondary forest fallow.

As the interplay of nitrogen and phosphorus is often marked, the bearing of the proportion of nitrate on the responses of field crops to phosphate must ever be remembered.

Growth of grasses produces greater fertility than forest

As organic matter is supremely important in the supply of plant nutrients to surface soils by the slow oxidation and in retaining moisture in the moderately excessive heat, the basic foundation of soil fertility in tropical conditions is the maintenance and improvement of organic matter. Excessive oxidation by cultivation and clearance of forests and exposure to strong light and wind and heavy rains accelerate organic matter oxidation and leads to the deterioration of soil physical properties. This may lead to the formation of unproductive soil from fertile condition.

Moderate to high total organic matter and therefore equilibrium carbon contents exist in some of the better drained alluvia in the tropical sub-humid wooded Savanna and mild sub-arid wooded Sevanna. In seasonal swamps or vleirs in the open grasslands of the Southern sub-trophics, their contents commonly are low compared with those in equivalent habitats in temperate climates.

It is well established that grasslands create greater soil fertility than neighbouring forests. The two reasons being the greater incorporation of the organic matter and smaller washing away of calcium phosphate and other minerals in the grassland than in the forest lands. That grass leads to the creation of fertility is well established.

The prairie land is dominated by tall luxuriant and deep rooted grasses. Over most prairie areas the rainfall varies from 20 to 40 inches. The earth's principal regions of original tall grasses are :

1. Parts of Central U. S. A. and Prairie States of Canada.
2. The Argentine Pampa, Uruguay and Southern-eastern Brazil.
3. Parts of Southern Russia.
4. The Danubian plains in Hungary and Rumania.
5. Possibly parts of Manchuria.

The steppe land, on the other hand, is composed of shorter shallow rooted grasses and exists in the semi-arid regions. In the U. S. A., steppe lands consisting of short grasses lie east of the Rocky mountains and west of 100 meridian. The

meagre rainfall comes in later spring and early summer or just during the growing season. Bunch grasses occur in regions west of the Rocky mountains in California, Washington, Oregon, Idaho and Western Montana.

Soil fertility depends both on the inorganic constitutents as well as on organic matter, which oxidise quickly with increase in soil temperature. The formation of rich soil, as in the prairie or chernozem, is chiefly due to the growth of tall grass; the roots of which can supply 2 tons or more of carbohydrate per acre. The oxidation of the root material aided by calcium phosphate and light absorption is conducive to nitrogen fixation and soil fertility improvement. It has been repeatedly stated that the mature soils of humid regions have developed under forests. In these lands the organic matter remains on the surface mainly and does not get mixed up with the soil as in the grasslands with penetrating root systems. Moreover, due to continuous washing aw·y by rain, the loss of lime, phosphate, potash is greater in the forest land than in grasslands. We have observed for a number of years that the lime, phosphate and nitrogenous contents of grasslands are greater than the nighbouring forest lands.

The steppe soils, like the prairie soils, have fine granular structures and dark colour rich in humus. Both these qualities are derived from the abundant and deep accumulation of grass-root organic matter. The rich Corn Belt soils of central Illinois, Iowa, Missouri are prairie soils and are developed in regions of old glacial rifts. Chernozem soils consist of black earth existing mostly in the U. S. A. and believed to be the best development of grasslands. It is formed under a thick vegetation of prairie and steppe grasses with an amount of precipitation low enough for the soluble minerals to be leached but abundance of lime, phosphate and other minerals remain in the land. The lime horizon lies within the reach of grass roots. Thus the lime supply is well ensured. The surface material of the Chernozem land is rich in humus and has a black or very dark-brown colour. Due to the presence of soluble calcium and magnesium salts, the soil colloids are well flocculated and have a granular and porous structure. The soil colloids make them plastic when wet. These are excellent lands for growing cotton, grains etc. that draw heavily upon the soil fertility. Excellent crop production is possible for a fairly long time without fertilizers. But, the humus and fertility are lost on continuous cultivation for a long time.

Adjacent to the Chernozems but in dry areas and with short grasses, the steppe soils are formed in temperate climates. They are fertile and form excellent regions for livestock grazing.

In this industrialised civilisation greater and greater amounts of nitrogenous fertilizers are being applied for intensive crop production at the neglect of the soil organic matter. Our researches clearly bring out that without organic matter, permanent agriculture is impossible, because, organic matter not only improves the physical conditions of soils as hitherto believed, but, Dhar and coworkers have definitely established that they fix atmospheric nitrogen and stabilise the soil or the added nitrogenous compounds. Also, they have proved that calcium phosphates and basic slags largely improve soil nitrogen fixation and soil fertility and bring down the carbon : nitrogen ratio of soils and make nitrogen more effective and available to crops. Consequently, organic matter and calcium phosphates form the cornerstone of soil fertility and crop production. Dhar and associates have experimentally established that the slow oxidation of the soil carbonaceous compounds by air is markedly intensified by the application of ammonium salts, urea etc. which produce in the soil nitrates, which help in the oxidation of soil organic matter. The formation and decomposition of the highly explosive and unstable substance, ammonium nitrite ($NH_4NO_2=2H_2O+N_2+718$ K. cals.) is inevitable

in soil processes on adding nitrogenous fertilizers or manures and this marked loss of nitrogen from soils explains the low recovery of nitrogen, *i.e.* of the order of 25 to 45%, when the nitrogenous fertilizers or manures are applied. This loss of nitrogen is partially avoided by incorporating organic matter. Madame Tardieux Roche of the Pasteur Institute, Paris, has shown that under acid conditions, the N/P value of systems containing small amounts of soil and rock phosphate in which microbial population is increasing, are much smaller than in neutral or alkaline systems, showing nitrogen fixation in larger amounts in alkaline systems by the oxidation of organic matter where the oxidation of organic matter and fixation of nitrogen is greater than in acid coditions.

On earth's surface, organic and inorganic forms are closely intermingled and intimately inter-related and from their combined patterns of distribution there emerges an earth's surface of variegated form and colour.

Summary

1. Calcium has an unique position amongst the plant nutrients in determining soil fertility because calcium clay is most favourable for the growth of plants. Chalk and lime neutralise soil acidity, form calcium salts in soils, which coagulate negative colloids like humus, silicic acid sol etc. and also increase soil porosity and texture. They help in the oxidation of humus and supply adequate plant neutrients. They decompose sparingly soluble phosphates of iron, aluminum, titanium etc. and convert them into calcium phosphates, which are more readily assimilated by crops. Moreover, calcium carbonate fixes atmospheric nitrogen by the slow oxidation of soil organic matter by air, and, there is a correlation between the lime and nitrogen contents of many soils.

2. All organic substances when incorporated in the soil undergo slow oxidation by air and lead to marked nitrogen fixation and increase of soil fertility. This is the most important function of the soil organic matter, which has other valuable properties also, *e. g.* increase of porosity, water retention capacity, support of micro-organisms etc. Moreover, the soil humus formed from organic matter adsorbs calcium ions, ammonium ions etc. and decreases their washing away.

Approximately, 360 million tons of available nitrogen are necessary for the production of food, fibre and fodder in the whole world, but, factory nitrogen supplies only 16–18 million tons, legumes supply 5 million tons, precipitation supplies 5-7 million tons and farmyard manure 5-7 million tons. Hence, these supply not more than 3% of the nitrogen need of the world crops. Dhar and co-workers have fixed large quantities of nitrogen in different world soils by the incorporation of all types of organic matter including straw, leaves, municipal waste, peat, lignite, bituminous coal etc. This type of nitrogen fixation is the main source of the world soil nitrogen, which is increased by the absorption of solar light and by the addition of calcium phosphates including rock phosphates and basic slags, which being alkaline help in the oxidation of organic matter and in the fixation of nitrogen and in the supply of other plant nutrients including trace elements. A mixture of organic matter and basic slag can increase fertility markedly and support permanent agriculture even in alkaline lands all over the world *without* the application of artificial fertilizers. Moreover, composting of organic matter is greatly improved by mixing it with calcium phosphates, and rich composts containing 2% total nitrogen and other plant food materials can be readily obtained from water hyacinth, municipal waste, straw etc. whilst the unphosphated Howard compost contains 0·5–0·8% total nitrogen. Basic slag has been

found to be more durable than superphosphate because the lime present in basic slag as well as in farmyard manure decreases the hydrolysis of calcium phosphate and checks its washing away. Consequently, it is of vital importance that the phosphate reserve of world soils must be increased by the application of cheap sources of phosphate like rock phosphates, basic slags etc. A mixture of phosphate and organic matter added together functions much better than when the two are applied separately.

3. Fertile soils are formed from earth's crust by the slow oxidation of plant materials including algae on the earth's surface. Fixation of N increases the fertility and plant growth, which further accelerate nitrogen fixation and increase of fertility by oxidation of the carbohydrates, fats etc. from photosynthesis. It has been found that nitrogen fixation in soils by blue green algae is much less than the fixation by incorporation of straw, leaves, weeds, municipal waste, specially fortified by calcium phosphates.

4. The formation of nitre beds in warm parts of the world like Chile, Peru etc. has been explained from the viewpoint of nitrogen fixation from the slow oxidation of sea weeds, planktons etc. mixed with guano or bird deposits or bones of fishes or animals in presence of strong sunlight. The nitrogenous compounds, originally present or fixed, undergo nitrification and form nitrites which are converted into nitrates of sodium, potassium etc. in the presence of alkali salts found in sea water. The soluble nitrates thus produced may be separated from calcium phosphate of bone or dung by washing down the highlands and accumulated in valleys by evaporation of the nitrate solutions.

5. The statistical results show that countries like Netherlands, Norway, Belgium, East Germany, Ceylon use larger amounts of nitrogenus fertilizers than other countries and the value of these fertilizers is much less in producing crops than in countries using smaller amounts of fertilizer nitrogen. But in Taiwan, Japan, China where a lot of composts, plant and vegetable wastes are utilised along with chemical fertilizers, better crop yields are produced per unit of nitrogen, because, the humus accentuates the value of introgenous fertilizers.

Experiments carried on in the U. S. A. and other countries show that fertilizer nitrogen added at greater rates than 100 Kgs. per hectare produces a depressing effect on various crops.

Denmark is highly advanced agriculturally and it has been reported there that by increasing the fertilizer consumption by 60%, the expected increase in crop yield is only 4%. Hence, the possibilities of the increased use of fertilizers are often overestimated and the law of diminishing return too often neglected.

In the U. S. A. the paying crops like cotton, tobacco, vegetables and fruits are well fertilized. To corn and small grain, phosphate and potash are adequate, but, nitrogen is low. For hay and pasture lands, application of fertilizers is very low. At least 6·5 million tons of nitrogen are lost from the 510 million acres of agricultural lands of the U. S. A. per annum.

6. All over the world, soil humus is decreasing because of the slow oxidation of organic matter by air aided by nitrates which are always formed on the application of nitrogenous fertilizers and manures. This decrease of humus causes a drop of crop production even when supported by fertilizers. This should be avoided by the ploughing in of straw mixed with rock phosphates and basic slags—the mixture helps nitrogen fixation and soil fertility permanently.

7. Marked nitrogen loss takes place when land is fertilized by commercial fertilizers and manures because in the process of nitrification of all types of nitrogenous compounds, the unstable and explosive substance, ammonium nitrite, is

formed and it decomposes according to the equation: $NH_4NO_2 = N_2 + 2H_2O + 718$ K. cals. This loss can be partially avoided by adding calcium phosphates which stabilise the nitrogenous compounds and by straw and other organic substances, which decrease nitrification and loss of nitrogen from soils.

Farmyard manure or straw mixed with artificials produces more crops than artificials alone. Direct ploughing in of organic matter like *straw*, which has been found to be an excellent fixer of atmospheric nitrogen and preserver of soil nitrogen, *water hyacinth*, rich in potash and nitrogen, *KANS*, *weeds*, *municipal wastes*, mixed with phosphates, produces more crops than from the compost obtained from them, because, there is more fixation of atmospheric nitrogen in direct ploughing than in composting.

8. Experimental observation shows that the nitrogen content of the Indian soils is greater than those of California, Texas etc. in the U. S. A. whilst those in Central and South America are greater than those in India. The nitrogen content of African soils in many cases is also high. This is due to the fact that in nitrogen fixation, sunlight is utilised and the greater nitrogen status of land near equator supports the photochemical viewpoint of nitrogen fixation advocated by Dhar for over 40 years.

9. Growth of grasses produces greater fertility than the forests, because, more than 2 tons of organic matter are normally incorporated from grass roots and these get mixed with the soil and fix atmospheric N. In forest lands, organic matter remains mainly on the top and does not get incorporated in the soil. More-over, forest lands remain more wet than grass lands and wash away minerals like calcium phosphate and nitrate which create fertility. For permanent agriculture all over the world, much greater utilisation of all types of organic matter including water hyacinth, weeds, straw, municipal waste, peat, lignite etc. mixed with cheap phosphate sources like basic slags, rock phosphates, are of permanent importance.

10. On earth's surface organic and inorganic matter is closely intermingled and the mixture should be utilised for improvement of land fertility and continu-ance of permanent agriculture all over the world.

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Food For The Future

By

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In the light of modern science, the Earth has the capacity to meet the food needs of billions more people than now exist. Very large acreages of good farming land are yet to be brought into production by clearing, leveling contouring, draining and irrigating. We now have the heavy earth-moving types of equipment required to get such land ready for agricultural use The productivity of much of the land now being farmed could be materially increased by growing better-bred crop plants, by using larger tonnages of fertilizer, and by a variety of other means with which we are all familiar.

Some highly important new developments for increasing food supplies are in the offing. We may be able in due time to produce entirely new species of crop plants, synthesized in accordance with planned specifications, by the acid of molecular biology. Production of sugar from carbon dioxide and water by factory procedures, in much the same way as the sugarcane plant does it, is a possibility. Once this was accomplished, we would then be on the way to unlimited production of high-protein foods by feeding the sugar, plus fertilizer chemicals, to microbes on a factory basis. While we are awaiting these developments we can proceed with the development of synthetic foods from petroleum and the culture of algae on a large scale.

To bring these undertakings into full fruition will require abundant supplies of energy over and above those now being derived from fossil fuels and falling water. But the answer to this need is already known and lies in the further development of nuclear energy, now provided by fission but ultimately by fusion as well. Why, then, is there so much pessimism about our being able to relieve the hunger that exists in so many parts of the world ?

Some years ago a scientist in India made an estimate of the possibilities of increasing agricultural production in his country over a period of the next half century. He proposed to make much greater use of the natural supplies of rainwater for irrigation purposes ; to improve the heritage of the crops now being grown ; to make much heavier applications of fertilizer ; and to develop much better methods of soil and crop management. His calculated gains in food production from these suggested improvements were very large indeed. But when he took into consideration the number of people there would be in India by the end of his 50-year period at the current rate of population growth, he discovered there would be less food per person then than before. To him the only way out was to lower the birth rate. As a starting point he suggested an effort be made to spread the concept that any woman who gave birth to more than three children was an improvident mother.

World population is now estimated at around 3½ billion. The average annual rate of increase is about 1·6 per cent. It will be recalled that Malthus, in

his *Essay on the Principle of Population,* published in 1798, pointed out that whereas food production increased arithmetrically population grew in geometric ratio. The only answer he could see to the problem of food shortages was the old one of war, famine and pestilence, which had long been highly effective. Malthus also mentioned moral restraint, but he was not impressed by its probabilities.

During recent years the world's peoples have succeeded fairly well in preventing war and pestilence from taking their heavy tolls. This has resulted in a faster rate of population growth and has added to the prominence of famine in its control. In spite of the tremendous potentialities for increased food production over the Earth at large, many millions of people go to bed hungry every night and many thousands of them actually die of starvation every year. Shipping food in from countries of surplus is not feasible on any adequate scale because of the high costs involved and the difficulties in transporting the imported food into the interiors of the countries in distress. Help must come mostly from within the nations of need, by improvement in agricultural practices and by organized control of human reproduction.

Dense populations overran India and China long before agricultural science had come into being. The same thing happened in the Valley of the Nile. There, as the population increased up to the limits set by the food supplies, a succession of dams was built to store more water for irrigating more desert. But each time the population rapidly overtook the larger quantities of food thus made available. It is likely to do so again, once the latest dam has been completed and still more water is available for irrigation purposes. The problems presented in these countries are not only those of meeting their immediate needs for more food but of overcoming economic and related troubles of long standing on a grand scale. None of these problems can be solved in a hurry. The time factor in their solution is extremely troublesome.

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Agricultural Soil problems and World famine

By

O. ARRHENIUS

The critical problem in the struggle against world wide famine is the explosive growth of the world population. This growth must in one way or other be stemmed. But this will take time. What we can gain by improving our agriculture is only a postponement of the catastrophe. The delay caused by this work may be our saving.

The areas we may win by bringing new land under cultivation are very small. We must, thus, mobilize all available forces to bear on the problem of improving the arable land now in use.

Here, however, we must not forget, as we often do, that those schemes which are successfully employed in Europe and in the U. S . A. cannot always be indiscriminately applied to other regions. To be successful a practical approach must be chosen on the basis of indigenous experience and local customs.

On the basis of a lifelong experience of agriculture and soil science in many parts of the world I will give a brief outline of those measures which in my opinion should be taken. I begin with those which would give most immediate results.

About 40% of the yields in many tropical countries are destroyed by rats, insects and moulds. The storage problem must be studied and measures taken against these losses. Only productive cattle may be used.

By the aid of irregation we have increased the yields of large areas. But we also have suffered extensive losses of land which as a consequence of the irrigation have been converted to more or less salt deserts. This has been the case particulary in basins with insufficient drainage. In this situation the salt must be removed from the stagnant groundwater by pumping and evaporating the water, removing the solids which partly may be utilized. Even big rivers are polluted by salt drain water to such an extent that the water in their lower course cannot be used for irrigation. Here also we must get rid of the salt of the drain water.

In order to maintain the fertility of the soils particulary in the tropics it is absolutely necessary to keep the humus content at a sufficient level. This can be achieved by green manuring. But it is absolutely necessary to utilize all straw and manure. Thus the burning of straw, offall and dung should be abolished. Over the whole world the city offall should be better used and not as now polluting the waters.

The problems of water flow and soil erosion must be solved. The destruction of forests must be stopped and immense areas reforested. In this way the present rate of erosion may be reduced considerably and the flow of water improved. Simultaneously the chemical denudation is decreased. The forest trees with their deep rooting are able to pump up nutrients from deep layers of the soil. The humus production from forests is greater than that of used grassland. The percolating water is enriched with regard to nutrients when passing through

the humus layers and in this way lower lying land is fertilized. Switzerland with its well kept forests and pastures is a good example how to fight denudation.

Physical and chemical examination of the soils gives us knowledge of their critical properties and suggestions for the realization of their potential production. The production of fertilizers must be increased. As mentioned above all refuse from man and animals must be properly processed and utilized.

An important factor contributing to the seriousness of the food situation is the lack of proteins. An investigation of common Swedish agricultural plants showed that some of them were extremely well suited for human and animal food as they were rich in proteins and had a full set of the essential amino acids. However efficient processing techniques are lacking. The old way of fermenting plant parts must be further developed and utilized.

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Productivity and Soil Fertility in Danish Agriculture

By

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Area and Crop Yield

The agricultural area of contemporary Denmark measures a little less than 3 million hectares (=7·2 mill. acres) and has been slowly shrinking for many years but still accounts for some 70 pct of the country (NB. exclusive of Greenland !). The soils are largely of glacial origin and vary in type from light sandy to medium heavy clay, with smaller areas of organic (moor and peat deposits) and heavy clay soils in salt marsh districts. Of the total area, about 1·5 mill. hectares are used for cereal cultivation and 0·4-0·5 mill. for root crops while most of the rest is pastures, either permanent (chiefly on low-land soils) or short-time leys in crop rotation on arable land.

The soils of Denmark are not as a whole remarkable for high natural fertility, but the crop yields have been approximately trebled since the turn of the century. Expressed in terms of "crop units" (equivalent of the feeding value of 100 kg barley grain), the total annual yields have for the last ten years varied around roughly 145 million units (maximum 156 mill. in 1964), compared to 50 mill. units sixty to seventy years ago. If we take the yield of wheat grain per unit area as a fair index for comparison between various countries, Denmark is seen to occupy the following position (based on average yields 1962–64) :

Country	Wheat Yield, 100 kg/ha	Country	Wheat Yield, 100 kg/ha
The Netherlands	48	Germany (DBR)	36
Denmark	42	France	31
Great Britain	41	U. S. A.	18
Belgium	39	Australia	14

The level of yield in Denmark must be called high but not unique among West European countries. Owing to increasing industrialization and urbanization only some 14–15 pct of the 4·6 million population of Denmark are today directly engaged in primary agricultural production, compared to 35 pct of a 3-milion population fifty years ago. This change in social structure has led to steadily increasing mechanization in the practice of farming.

Factors in Productivity

Multiple causes are responsible for the fact that a quite high level of productivity has been reached and (so far) maintained. One factor is naturally defined : a climate typical of the cool temperate regions, with no extreme variations in either temperature or amount and distribution of precipitation. Another

(social) factor is the existence of a rural population whose level of education compares favourably with that of other social groups here and in neighbour countries. A related and highly important factor is the close contact between practical farming and agricultural research, mediated by a highly developed advisory service. Higher education in agricultural science is more than 100 years old, and a staff of about 200 advisers on a level of B.Sc. Agr. are constantly engaged, not as Government officials but as employees of the farmers' associations, in making the results of Government research work on crop production available in farming practice. In addition to the experimental work at Government institutions a very large number of field trials with new plant varieties and fertilizers are conducted by the farmers' associations under the guidance of the advisers.

Contributory factors in raising the level of crop yields have been such measures as land reclamation and amendment, the introduction of improved plant varieties, control of plant diseases, insect pests and weeds by chemical means, and not least improved crop nutrition by rational use of fertilizers and soil amendments.

Obviously a threefold increase in crop yield during two-thirds of a century must imply a corresponding removal of plant nutrients and would result in a serious exhaustion of the land unless compensated in some way such as by increased use of fertilizers. In fact, the consumption of industrial fertilizers has increased on a scale that parallels the increase in crop yield, as may be seen from the following figures :

Year	Plant nutrients in industrial fertilizers, 1000 tons per annum			Total yield, crop units per annum	Population millions
	N	P	K		
1880 (*ca*)	–	–	–	40	2·0
1900 (*ca*)	1	4	2	50	2·5
1920 (*ca*)	13	12	7	65	3·0
1939–40	38	29	34	110	–
1950–51	69	36	81	130	–
1960–61	124	50	143	145–150 in Million	4·5
1964–65	168	54	150		

Phosphorus is mainly supplied in the form of superphosphate, potassium in high-grade potash salts, nitrogen quite predominantly as nitrate of lime until recent years when nitro-chalk and anhydrous ammonia have become important. For purposes of rationalization mixed N-P-K fertilizers have come on the market, sometimes enriched with magnesium and micro-nutrients. The incorporation of pesticides in fertilizers is not permitted.

This mass of plant nutrients is applied on top of the farmyard manure from roughly 3·3 million heads of cattle and 8 to 9 million pigs. Horses and sheep are insignificant, numbering (ca) 50,000 and 90,000 animals, respectively. Due to modern sanitation human excreta are practically lost to the soil. The amounts of the three major plant nutrients in the annual production of solid and liquid farmyard manure may be roughly estimated at 140,000 tons of nitrogen, 40,000 tons of phosphorus and 100,000 tons of potassium. About half of the nitrogen is present as immediately plant-available ammonia.

Into this production of farmyard manure enters a considerable proportion of the plant nutrients in oil cakes and cereals imported as feeding stuffs (approx. 1·0 and 0·7 mill. tons, respectively), further some of the biologically fixed nitrogen of pasture legumes (clovers and lucerne).

It is important to notice that the distribution of the farmyard manure is by no means uniform, because there has for a number of years been a tendency to abandon dairy farming in the eastern parts of the country, and although the cattle population remains fairly constant, it tends to ' migrate westward".

In addition to the fertilizers proper, agricultural lime in amounts corresponding to about 0·8 million tons calcium carbonate is annually used as a soil amendment to correct soil acidity following the leaching of dissolved calcium from the soil (the annual precipitation in Denmark is 660 mm, with a runoff corresponding to 280 mm).

Soil Testing

Soil testing for advisory purposes began in 1910 in a small way (biological testing for lime requirement) but is today widely used as a guide for the use of fertilizers and soil amendments. Altogether 23 major and minor laboratories are operating, on government license and under government inspection. A total of roughly one-half million single determinations are made annually, with soil pH, phosphorus and exchangeable potassium ("standard analysis") accounting for nearly two-thirds. Other tests include conductivity, base exchange capacity, magnesium, copper, manganese, boron, etc. By far the greatest number of soil samples are collected by the agricultural and horticultural advisers who also assist the members of their associations with the interpretation of the analytical results.

Changes in "Soil Fertility"?

The causal connection between fertilizer consumption and crop yield seems obvious, but it is much more difficult to tell if soil "fertility" has increased or decreased during the period in question—at least if "fertility" is understood as the ability of the soil to produce crops without fertilizer supplements. Typical field soil contain little more than 1000 p. p. m. organic nitrogen, and this element would soon become a limiting factor without extra supplements. Long-term field experiments have shown that under a crop rotation with a leguminous crop every fourth year the yields gradually drop to a low level where they become constant. Only the limited areas of lowmoor and fen soils contain large nitrogen reserves, and gains of nitrogen by symbiotic fixation are difficult to assess and would essentially be due to pasture legumes. Seed legumes like peas, beans and lupines are minor crops only, and nonsymbiotic nitrogen-fixing bacteria are unfavourably placed in an agricultural system with such copious use of mineral nitrogenous fertilizers.

The long-continued use of phosphatic fertilizers seems to have built up a fair soil-reserve of this element, as shown by the fact that only a minor decline in crop yield took place during the Second World War when the import of rock phosphate and manufacture of superphosphate were interrupted ("A phosphate fertilizer experiment on a gigantic scale"). Superphosphate is therefore nowadays employed chiefly for maintaining the phosphorus state of soils. Potassium reserves on the other hand seem to be difficult to build up, and the spontaneous release of potassium ions from clay minerals is much too slow a process to maintain high-level crop yields.

Recent evidence suggests increasing frequency of magnesium deficiency and the existence of a negative magnesium balance, and also deficiencies of (*inter alia*) copper and boron seem to be on the increase—probably owing to the heavier drain on soil reserves through the increasing crop yields, while the return of the elements to the soil remains more or less constant. This is why the use of fertilizers enriched with micronutrients is gaining favour among the farmers.

A "humus problem" has hitherto scarcely existed. Really rapid loss of soil organic matter has only been observed in highmoor peat under recent cultivation, and long-term experiments on mineral field soils have failed to show any significant change in humus contents of plots given mineral fertilizers for more than half a century, whereas permanent use of farmyard manure has only resulted in a slight humus accumulation. This, indeed, applies to soils under a "conventional" rotation of cereals, root crops and clover-grass mixture and might not necessarily be true under changed systems of cultivation. Actually there has for several years in some parts of the country been a tendency to do away with domestic animals (af. above) and concentrate on cereals and industrial crops. Moreover, with the advent of the combine harvester and under a severe shortage of agricultural labour many farmers find it economically preferable to burn the straw in the fields—which means a strongly lessened return of humus-farming materials to the soil.—Actually it is realized that changed crop rotations with predominant cereal growing may create new and serious problems, first and foremost consisting in the spread of soil-borne plant pathogens, but eventually also undesirable changes in soil structure that may not be quickly remedied—all important matters to be considered in the planning of future research.

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Agricultural Trends and Soil Fertility in Sweden

By

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The climate of Sweden is mediun humid. The soils, mostly sedimetary clays and loams, are somewhat podsolized in the greater part of the country, a soil reaction of pH 5·0 to 6·0 is common. Only in some areas with a less humid climate, the soil reaction is neutral. The yearly precipitation range between 500 and 1,000 millimetres, (20 to 40 inches). The humus content of the soil varies with climate and type of farming. In the most humid regions, where animal husbandry, mostly dairy farming, prevails, the humus content is often 5 per cent or more. Within the more arid regions, where a more intense farming is common, the humus content is lower, sometime below 3 per cent. The growing season is in south Sweden, around 55°N, about 6 months. An intense farming including growing of sugar beets is dominating on good soils ; on sandy soils large areas of potatoes are grown. In middle Sweden, 50° to 60°N, wheat growing is of main interest on the fertile plains, mixed framing in the forrested areas. The growing season is about 5 months. In northen Sweden, up to around 68°N farming conditions are hard. The growing season is in the far north less than 4 months. Only early ripening barley, grass and potatoes can be grown. Fortunately the farms do not include only arable land, large areas of forest help to make living possible.

Sweden was earlier an agricultural country. In the writers boyhood, sixty years ago, more than 40 per cent of the population was agricultural. Especially after World War II a rapid change has taken place. On large farms and estates an extensive mechanisation has taken place and reduced labour to less than 10 per cent of earlier requirement. Also on family farms the mechanisation has been revolutionizing, the children leaving the farm as soon as they can get employment in the fast growing industry, and many small farms have been abandoned, mostly taken over by some neighbour. At present less than 10 per cent of the population is engaged in agriculture ; the industry is dominating. And politically, the trend is to reduce farming still more, to concentrate farming only to the fertile plains and plant forrets on the farmland in the forested areas. The reasoning is that it is necessary to decrease the cost of living for the industrial population by buying cheap food on the world market instead of expensive food grown within the country. Undoubtly, the cost of living is high, but the cost is not caused by the farming. Of the cost of living about 28 to 30 per cent goes to food, but of this cost only about 8 per cent goes to the Swedish farmer. When the writer was a small boy, grain for bread making cost about 3 U. S. cent per kilogramme. The bread, the crisp rye bread, the common bread in Sweden, did at that time cost about 6 U S. cent per kilogramme. At present the farmer gets about 10 cent per kilogramme for the grain, but the bread cost more than 60 cent per kilogramme. The increased food prices are not caused by the farmer. The really pinching in the cost of living is the rent for the apartment, owing to a very high standard of apartments and a very high building cost. The high rents have caused an elaborate system of state rent subventions. At the last election it was

discovered that even the Prime Minister enjoys rent subventions. By blaming the farmers for the high cost of living the much more important question of the rent is comouflaged.

The old type of farming in Sweden was predominantly dairy farming. Only on large farms and estates on the fertile plains some grain growing was of importance, Sugar beets and potatoes were grown in special areas. Especially after World War II a great change has taken place. The high cost of labour has forced to mechanization. Grain growing can be highly mechanized, hence, grain growing has increased. On large farms and on many small ones the dairy cows—often all animals— have disappeared. And this trend toward increased grain growing and decreased growing of cattle feeds will perceptible influence the fertility of the soil. Especially the question of humus preservation will be of importance. The trend is simply wrong from almost every point of view. A few points will be discussed later on.

One of the most striking features in Swedish farming of today is the gradual disappearing of liming during the last 20 years. The problem has some bearing on soil fertility. Of old liming has been proclaimed to be of fundamental importance for acid soils. When the technic of pH determinations was adopted to soils the liming propaganda got a powerful impetus. However, the writer was sceptical. Observations on the parental farm some six years ago gave the idea that a suitable nutrition was able to forestall the detrimental effect of an acid reaction. In the late twenties and early thirties it was possible to show conclusively, that soil reaction had no influence on crop yields between pH 5 and pH 8, a suitable nutrition being the only determining factor. A method of chemical analysis of soils made it possible to calculate the amounts of fertilizers in kilogrammes per hectare necessary for an optimal yield. The amounts calculated were always much less than the amounts recommended in the propaganda and by state institutions. By mixing phosphate and potash fertilizers with farmyard manure or other organic material the fixation by the soils was prevented, hence small amounts of fertilizers were sufficient for large yields. With this method of fertilization it was found in a very comprehensive investigation based on field experiments that liming up to neutrality was without importance. Common amounts of lime gave no increase in yields, large amounts gave so small increase in yields, that they were not profitable. Liming had no perceptible influence on the value of the crops, either chemically or ascertained by feeding experiments. The effect of liming is primarily a hastening of the decomposition of soil humus, an unwanted effect. The result of the thorough investigations was that the farmers use of lime began to decrease very rapidly in spite of the commercial propaganda and the support given to this propaganda by state institutions. However, a plan for testing on a country-wide basis that new idea of *standard fertilization* as the new method of calculated fertilization was called, was after a couple of years stopped by pressure groups. The minister of agriculture was forced to cut out the grant that made the investigation possible. However, liming could not be revived. And calculations have disclosed that the farmers have gained at least 50 million dollars from the results of the investigations. (And the fact that the investigations were stopped about ten years ago made it possible for the writer to find time for work on his theory of complete tooth nutrition. According to this theory dental caries is a deficiency disease caused by an insufficient supply of tooth nutrients, primarily during tooth formation. By adding suitable tooth nutrients to a common daily fare caries—free children have been raised. When the theory of complete tooth nutrition becomes utilized, dental caries will disappear. This parenthesis has been added in order to encourage young scientists, that find their ideas blocked; Try some other idea ! We need new ideas).

The present political trend in Sweden is to continue farming only on the plains in central and southern parts of the country. On the rest of present farming land forests should be grown. The food shortage should be filled from the world market. That is a plan completely wrong. As the farmers part of the cost of living is only 8 percent a small reduction of that part would have no influence on the cost of living. And in a few decades the population explosion will increase world population so that every square metre is needed for food production. Shall we then cut down the forests on the previous farming land ? That will be hard job, indeed. The plan is simply an attempt to divert the interest of the public from the high cost of appartment rent to the high food prices. The fact that the farmers are responsible to only 8 per cent of the cost of living is a fact not mentioned.

The trend in farming practice to increase grain production and decrease dairy farming is also wrong in the long run. Grain production tend to impair the soil, especially if the straw is burned, but even if the straw is ploughed under soil fertility will decrease. Straw alone seems to make a second class humus. To stop the decrease in fertility increasing amounts of artificial fertilizers are recommended and used. But the effect of artificial fertilizers is decreasing. When the writer sixty years ago introduced phosphate fertilizers as a supplement to farmyard manure on the parental daily farm, the response was tremendous. At present the response is far, far less. And the famous soil scientist Sante Mattson (1966) has shown that an excessive use of nitrate fertilizers—the most effective in raising crop yields—induces such a disturbed ion absorption by the plants, that the quality is impaired. That is a finding that probably will be ignored or hotly disputed in a world where the amount of fertilizers used is a measure of agricultural standard. Increased grain production will—among other thing—decrease humus content and thus impair soil fertility. Artificial fertilizers offer no help.

Cattle on a farm will in several ways promote soil fertility. On pastures the humus content is increasing. And in a rotation including a large percentage of fodder, especially clover and grasses for hay and silage, the plowing under of the sod will form humus of a good quality. And farmyard manure acts a rejuvinant or of soil fertility. Dairy farming is decreasing not only because it is labour consuming and hard to mechanize. It is also a question of over production. The milk production of the cows is rapidly increasing. At least two factors can be mentioned : the increased spread of an almost scientific feeding and artificial insemination, so that only bulls of supreme hereditary quality are used. Of the Swedish cows more than 1/3 are controlled and the produce around 5,000 kilogrammes of milk and 200 kilogrammes of butter fat. (Average for all cows is around 3,750 milk and 140 butterfat.) And the figures are increasing. And such cows should be exterminated ! ! ! And there is no danger in over-production. Half the world is starving. Any over-production could be sent out to the starving countries. Dry milk is easily manufactured and easily transported any where around the world. It is a very valuable protein supplement, especially for children. Sweden is yearly spending more than 50 million dollars for support of undeveloped countries. If a part of these million were sent in the form of dry milk, there would be a help to decrease child starvation, and it would help to preserve a form of farming that could very well be carried on in those parts of Sweden where its existence is threatened, and it would help to preserve or even enhance soil fertility.

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Problems and Possibilities of Dryland in Central Spain

By

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Introduction

In order to offer the subject with a little more detail we only touch the problem of the conditions of fertility in the Central Region of Spain which is mainly applied to dryland wheat cultivation.

The mean yields of wheat in Spain, including irrigated land, has been in the last years of about 1·200 Kg/Ha, which represents a mean yield for dryland—which is the greatest part of the surface devoted to this cultivation —of some 700 to 800 Kg/Ha. This yield is among the lowest in Europe.

We could think that the mean reason for such a poor yield were the scarce rainfalls, which is what the farmer believes. That is also why he shows no enthusiasm for the use of fertilizers as he supposes and in fact has often experienced that on increasing fertilization, yields decrease or at least do not increase economically.

According to these facts it seems that only irrigation can produce higher yields, but our experience has often showed that this is not the reason of the yields obtained. (*See* for example : (1), (2), (3) and (4)).

Fertility conditions

In a detailed study of the conditions of fertility of the Province of Guadalajara (belonging to the Central Region) (5) we have been able to confirm, by the analysis carried out, that there is a great unbalance in the level of fertilizing elements and that even in those soils where farmers think the yield is good (over 1.500 Kg/Ha) the fertility level doesn't go above a mean type and is therefore possible to increase it, with adequate fertilization.

That fertilizaticn is an important factor can be inferred in this particular case, from the results obtained in that study :

Zone	Low Yield					Medium Yield					High Yield				
	N%	C/N	Mat. org.	P_2O_5 mg%g.	K_2O mg%g.	N%	C/N	Mat. org.	P_2O_5 mg%g.	K_2O mg%g.	N%	C/N	Mat. org.	P_2O_5 mg%g.	K_2O mg%g.
Lowland Henares	0,055	7,53	0,68	3,5	29	0,064	7,48	0,83	11	26	0,090	9,92	1,52	39	39
Highlands Henares	0,075	11,43	1,37	4,4	27,7	0,096	9,36	1,58	13	40	0,116	11,55	3,23	14,6	43
Sierra	0,096	9,58	1,35	4,5	34,0	0,133	13,72	3,16	12,5	37,7	0,166	14,35	3,71	38	43,2
Alcarria	0,112	10,30	1,12	4,4	35	0,127	9,00	1,90	9,6	35,5	0,129	10,37	2,18	16,5	41
General mean	0,088	10,26	1,47	4,1	31	0,108	10,01	1,93	11,5	36	0,127	11,57	2,44	26	43

However, the later experimentation based on these same results, showed that when the values of fertility levels inferred from the soil analysis correspond to the idea of high yield, the amounts of fertilization necessary for the highest yield is the normal one among farmers ; varying in each element according to the needs of the soil and that is where the farmers fail when they apply the same treatments to soils with different balance of nutrients.

In systematic experimentation, during 8–10 years in farms, we have been able to observe that when rainfalls are lower than 400 mm (350–400), the yield stays between 1·500–2·000 Kg/Ha when fertilization is adequate, that is much higher than the mean value of the whole country, which, as we said before, is not above 1·200 Kg/Ha., including irrigated land. But we have to add that these yields cannot be obtained exclusively with convenient fertilization, but should also be complemented by adequate crops rotation in order to maintain the good yields along the years. But we shall come back to this later on.

Fertilization

In relation to the levels of fertility, we must say the results obtained are much more heterogenous that those corresponding to the physical study of the different soils of an area.

As we said before, there is great unbalance at the level of fertilizers and therefore the previous study of the conditions of fertility by the analysis of the soil is necessary in most of the cases in order to learn what fertilization is more convenient. Anyway, and this is the general case in the Central Region of Spain, where we have carried out our research, nitrogen is the fundamental element where deficiency shows most clearly in the cultivation of wheat, except in single cases which needn't be mentioned.

But as the nitrogenous fertilizer is the most expensive the farmer finds himself in difficulties, even in spite of the aid the State grants him. The State grants economical help to buy fertilizers and allows farmers to pay the money back when they have harvested, which is a great financial help and even, in cases of great losses or catastrophe caused by climatic phenomene, they have only to pay back part of the loan and in some cases nothing at all.

In spite of everything the statal help is not sufficient for every farmer to be able to apply the amount that is necessary and logically, help is only partial and it is always the poorer farms which need more help get less.

Besides, the real solution would be that most of these areas should be devoted to grassland which would normally allow to get a more adequate production with the same inversion needed for cereal or cereal-leguminous.

However we must observe that, within our means, much has been done and this is the reason for the increase of the mean yield in our Country in these last years, as we said before.

The farmer, mainly because of its price and the effects observed, prefers to use phosphate fertilizers more in harmony with the needs of the soil, than nitrogenous and potassic ones.

The nitrogenous fertilizer is usually applied in smaller amounts than needed, because of its price, as we said before, and the potassic fertilizer because it is more difficult to see the effects clearly. A more technical knowledge is necessary and the farmer does not generally possess it. That is why the appearance of mixed and complex fertilizers has helped the potassic fertilization to have a broader utilization among the farmers who buy these products ; but at present the

preparation of these fertilizers is not general and still less is its use, as the cost per unit is logically higher as the contents in fertilizer is higher. The cultural level of the farmer is not high enough to make him understand these differences, specially if he doubts if they really exist.

As for the use of nitrogenous fertilizer, which gives the most spectacular and clear results for the farmer, apart from the cost, there is another reason why the farmer does not use it in adequate doses. It is because the previous analysis of the soil is not generalized and by not applying the correct amounts of phosphates and potash there appears the lodging of wheat and as a consequence of this, in the following years the amount applied is much below the necessary.

That is why, even though Science has not advanced very much in the use of fertilizers, it is clear that farmers are far from taking advantage of everything known and therefore the output is very much below that which should be obtained.

The normal application of fertilizers is 20 to 40 Nitrogen units, 40 to 60 of P_2O_5 and 0·50 of K_2O, which is almost always below the necessary to obtain the 1.500 Kg/Ha. of wheat and, of course, still farther from what is needed to obtain higher yields, which can be obtained according to the climate of different areas.

When rainfalls are higher and climatic conditions (frost, etc.) are favourable, better results can be obtained in dryland, and mean yields of 3.000 or even 4.000 Kg/Ha. can be obtained. These yields are obtained with much higher fertilizations. Normally the dose of nitrogenous fertilizer must be of the order of 100 units Nitrogen, and sometimes 120, and only farmers of a high financial level can apply these doses. Thus arises the problem that when conditions are more favourable to obtain better yields only those farmers who have adequate economic means are able to afford the necessary amounts of fertilizers. Of course this difficulty cannot be solved by the State and therefore we reach a point where the economic problem of investment on the land becomes fundamental if the yields have to be raised.

Add to this, the fact that the farmer lacks generally of a technical knowledge; we have the two main factors that are fundamental in the Spanish dryland Agriculture, to obtain the yields which would respond to the climatology and general soil conditions of our country.

Therefore an increase in the inversion on the farms is needed and also a better cultural, training of the farmers if we want to obtain this increase in production which will not only benefit our country but in the long run will benefit the whole population of the world.

When referring to phosphatic fertilization we see that with adequate varieties and when rainfalls are convenient, 500 or more millimetres, and the weather and other factors are adequate, to the soils of natural fertility of a medium type, doses of 100 units P_2O_5 can be applied, or even up to 150.

As to potash, the needs are in general lower, but in some cases, because of their characteristics of being calcareous soils or in other cases their characteristics of aeration, the dose should be higher than the one normally applied and of course for some varieties of wheat and on certain soils, doses of up to 250 or even more units of K_2O are needed.

The fertilization data we have just been giving offer a view on the needs of the soils and refer to soils of a medium type and in zones where rainfalls are above 500 millimetres, that is, where it is possible to obtain yields of the order of 3.000 to 4.000 Kg/Ha.

In general, the doses that are applied are far below the ones mentioned here.

The Administration is very directly supporting the building up of new fertilizers plants with which we hope that in a near future greater possibilities of applying fertilizers will exist in our country ; but the most difficult aspect is the fact that capital goes to the farms, but this—with the actual rentabilities—is completely utopian. It is not possible to think that this aspect will improve directly, that is why we think the action of the State can be of great efficacy.

At the moment, for all the reasons mentioned so far, the use of fertilizers is one of the lowest in Europe.

But fertilization is not the only problem, there are other factors which we are going to deal with next.

Organic matter

As we have been able to observe when considering the fertility conditions, the level of organic matter is in general very low and therefore the method to increase the amount of it in the soils, have been of great importance.

To make cultivation easier, stubbles were burnt and thus the level of organic matter decreased more quickly.

Today, it is not only recommended to leave the stubbles, but also the straw cut by the combines, and in this way, with not much labour, they can be incorporated to the soil and their decomposition is then easier, especially during the rainy periods.

If next autumn the leguminous is sowed, the organic matter buried, poor in nitrogen, can be decomposed more quickly by the action of nitrogen fixed by the rhizobium of the leguminous, this action is increased with nitrogen deficiency. In this way not only a greater yield of leguminous is achieved but also an increase of the organic nitrogen in the soil.

Even in the case when a leguminous grows after, we have observed an increase of the nitrogen in the soil, possibly as a consequence of photochemical fixation, such as Dr. Dhar (6) has observed more than once.

This increase in nitrogen is shown in the form of a better yield the next year.

The utilization of town waste material, which has been carried out for some years in some of the larger towns of Spain, has not brought forth a clear improvement in this field for the farmers, because besides the cost of the produce there is the cost of transport and usually the most important agricultural farming areas are farthest from the larger towns and therefore their utilization cannot be afforded.

It is more logic in relation to the last point and especially more efficient and economical to use the leguminous crop as green manure which leaves a great amount of organic matter residues in the soil. If we can also say that the cultivation of leguminous fixes Nitrogen, the most deficient element,—as growing of cereals shows—because in the way mentioned above, we can obtain an improvement in the level of nitrogen in the soil through the fixation of this element by the rhizobium of leguminous roots.

In this aspect it is advised to the farmers to try to inoculate the seeds, as it is necessary to confirm that in soils which produce leguminous every two years with good results, the level of the rhizobium is adequate and particularly active in order to obtain the highest results in the fixation of nitrogen.

Physical Conditions

As to the physical conditions of soils, texture and structure and the natural drainage, they are mostly rather favourable ; of course there are cases where it is not easy from the economical point of view, to resolve problems due to compactness (4).

The most difficult problem lies in relation to the shallow soils or the high contents of gravel in it and then the soils are not much use to grow cereals. Actually these soils have this use as a consequence of difficulties after our Civil War when it was ordered to grow wheat in these areas, and today because of the market-prices this situation goes on. And this is also partly the consequence of the inertia of the farmers to get away from cereals which have been cultivating traditionally but with which it is from year to year more difficult to subsist, and that is why there have been those massive exodus of country people to the towns in order to increase the posibilities of work with better wages than in the country, increasing with the industrial development.

We have already said, and everybody knows it because I think it is a general fact in every country that farmers have a great tendency to inertia and a difficulty greater than in other ways of life to change their activity, not only regarding farming but also and more so, when they ought to àbandon the traditional system and change their agricultural activity for an industrial one, so that when the change has to be undergone it is due to a great economical unbalance.

In shallow deep areas, steep slope, etc., pastures should be introduced, with subclover trifolium subterraneum as main seed and where fertility is lower, the vetch in the rotation should be exchanged for several years by subclover. In this case it will be necessary to select the stock that give the best results, and study the possibilities of acclimatization in each case. Therefore a research survey is necessary here.

Crops Rotation

We have been able to observe that rotation of cereals-leguminous especially vetch, which grows very well in the area studied, because the climatic conditions are quite adequate for it, results in a better efficiency for fertilization and higher yields in the wheat that grows after, within the possibilities of the climatic conditions of the area.

Besides, with system we practically suppress the fallow which is reduced to one every eight or ten years, very often less and depending only on the extension of weeds which cannot be completely eradicated by the action of weed-killers, although lately with the advancements in this field such good results have been obtained that the need of a year in fallow can still be put off the expenses of which logically reduce the general yield and which also increases the dangers of erosion.

Besides, there also exists the advantage that the growing of leguminous produces food, which cut green and silage can be used for feeding young cattle which can represent an important entry in the exploitation and furthermore, makes it more complete as agriculture has no logical sense without livestock, which has also been the reason for a difficult organic fertilization of the soils, and above all, the lack of meat cattle especially in the Central Area of Spain.

That is to say that an improvement from the point of view of the production of cereal, conveys an improvement in the meat production, both complete each other and five a livestock-agriculture, which is really what should always have existed. But the quality of the pastures is not good, because the farmer's technical knowledge is very deficient, for that, it is economically a bad enterprise and accordingly they have gone over to one-crop-farming. And this has been the

cause, or at least one of the causes for the impoverishment of soils and also for the fact that yields have got so deficient that today it is impossible for the farmer in his present economical state to buy the fertilizers needed for a possible improvement and particularly the use of organic dung which are getting scarcer every day, because of the lack of livestock.

Formerly this problem was reduced because of the growing of leguminous in the rotation. But for the last 10 or 15 years the difficulty of finding hand-workers to harvest the grain and the lack of harvesting machinery on the world market caused these crops to be abandoned with the result of fallow-cereal which is so pernicious.

Erosion

Some of the other aspects that have to be taken into consideration are also related to the facts shown so far, as for example : erosion.

The cereal area in the Central Region of Spain is mainly an one of slopes, more or less steep but always subject to erosion, sometimes a very strong one. To avoid this, logically, a cultivation is convenient along the curves of level and in this way the danger of heavy erosion is under control. Also the protection of plants is needed and that is why the cultivation of green leguminous instead of the traditional fallow is good for the soil when rainfalls are heavy. Besides, these rainfalls are usually very heavy although occasional, so that in a short time a great amount of water fall on the ground and the erosion process is then usually quite strong.

The presence of leguminous allows to slow down.

If we take into account that rainfalls of the Central Region of Spain takes place in autumn, winter and spring, with the system we have proposed eight or ten years ago and which many farmers have been following, we slow down the danger of erosion ; with cereal-leguminous rotation instead of fallow-cereal, we can obtain an increase in the total.

Ploughing

Another important aspect is the tilling of the soil. The observation we have made on this aspect, during the period of experimentation, is that it is convenient that ploughing are not deep and it is especially convenient not to work the soil with a moldboard plough because in this way the organic matter which lies on the surface stays there and in this way we have a surface layer with a soft quality and no breaking up of the surface can occur.

In the moldboard plough the organic matter gets pushed in depth and if it is true that in this way it lasts longer in the soil. it is also true that the surface presents less organic matter and therefore breaks up more easily, builds up a crust that prevents the penetration of water and contributes to increase, if possible, the dangers of erosion and the usefulness of rainfall.

Only when leguminous are put into the soil can the tillage be carried out at greater depth, but even in this case, not too deep as we have observed that if this organic matter is only half buried in the soil eases its decomposition and gives the soil a greater sponginess thus increasing the water-retention capacity.

Wheat Strains

We have to add something referring to varieties, as in this aspect we have only mentioned a few facts which should complete. The study of convenient varieties and which give better yields, is very interesting for the region and this

would allow to increase the yields obtained so far independently from the other factors so, for example with the use of short straw wheat strain it may be possible to obtain much higher yields with the same rainfalls and probably in the area below 400 mm rainfalls we could reach the 2.000 Kg/Ha. and 4.000 in the area above 500 mm.

Today, the strain "Etoile de Choisy", in areas where it can develop normally, and when fertilization is convenient, it is even possible to reach the 5.000 Kg/Ha. and exceptionally more, with rainfalls of about 550 mm. This fact gives an idea of the possibilities of the varieties, even more so if we bear in mind that with the same soil conditions, with another variety that is good for that area, as is Aragon 03, we cannot get more than 3.000 or at most 3.200 Kg/Ha.

Therefore, concluding from what we have exposed we must say that the analysis of soil fertility, the physical conditions of the soil—though not so important because of the great homogeneity of these conditions in general in every areas—together with the possibilities of climatology and precisely the factor rainfalls, we find ourselves in condition of being able to evaluate in every particular case the highest yields that can be obtained with the variety most adequate for the area.

However in the aspect of varieties there exist many possibilities and we think that in future research on this aspect should be increased in our country in order to obtain better yields than what at the moment can be considered the utmost.

Land Consolidation

We have not touched another interesting point which is important but perhaps a little beside the facts we have been talking about that which are of a much more technical character and related to fertility. But when speaking about the economical problem we can't avoid including for some regions, and especially for the Central one, that is the joining together of scattered holdings, generally divided by heritage problems.

Today the State carries out great investments in land consolidation, but this is not enough for the present moment and what is really necessary is joining the land of a whole village and building up an agricultural co-operative for common exploitation. This has been started some years ago in a village of the province of Navarra (Zuniga) in the North of Spain ; then it has expanded to other villages and there are even co-operatives for several villages, which in this way have more financial means, mecanization is simpler and there are more possibilities of carrying out a convenient soil ploughing ; all this, together with the use of convenient varieties and the most adequate fertilization according to the needs of the soils, produces wonderful results. It also facilitates market possibilities and allows to sell in more favourable conditions. The management difficulties are the most important problems in the development of these co-operatives.

Conclusions

It is convenient to summarize the aspects we consider most important to improve the rentability of the Region considered, as conclusions of everything we have been showing.

It is necessary : 1st) To increase the investments both in equipments and in a good technical training of farmers. The latter will have the consequence of quickly expanding the utilization of soil analysis and leaf analysis as to advisore to the farmers on needs in fertilizers for the crops.

2nd) The maximum use in the farms of vegetal residues of the crops.

3rd) Rotations where leguminous are used in order to be cut green, which doesn't have the difficulties of harvest for grain.

4th) Reserve for pastures (including preferably subclover (Trifolium subterraneum in the marginal areas on very steep slopes, high contents of gravel or with shallow soils (under 40-50 cm. deep).

5th) Supply fertilizers in very favourable economic conditions to pay part of the price for the administration especially the mixed and complex ones.

6th) Follow all the other ideas mentioned in the present paper.

And as a very important question, besides distributing the investments in machinery and other implements, promoted or offered by the Government itself, a training of the farmers in technical knowledge is also very necessary so that they will be able to avail the knowledge that Science can offer them, and on the other hand the investments and economic help especially in fertilizers so as to reach the yields that can only be attained with adequate fertilization.

With all that it should be possible to double the present yields, in a few years and even to surpass them, without such high expenses as irrigation need, and with much more secure and immediate rentability. Besides, these ideas can be applied to all kinds of soils without irrigation, that is, they have a more general and immediate character.

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Soil Fertility and Agricultural Production in India

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Of the 326·3 million hectares that comprise the geographical area of India, 174·9 million hectares can be used for agricultural purposes (Table 1). Land under forest totals 52·7 million hectares.

TABLE 1

Classification of land with potential agricultural use (1960–61)*

Type of land	Area (million hectares)
Net area sown	132·6
Current fallows	11·4
Fallow land other than current fallows	11·4
Cultivable wastes other than fallows	19·5
Total :	174·9

*Statistics and Survey Division, Planning Commission, December, 1963.

Flat land is in great demand by modern town planners who vigorously compete for it. In 1961 the population of the Indian Union was 438 million ; the per annum rate of increase since then is 2·15 percent. Towns are spread out throughout with increasing demand for land for transportation and recreational purposes. The combined effect of population increase and "spread-out" towns on the per capital area of cultivated land is illustrated in the trend from 1921–1961 shown in table 2.

TABLE 2

Per capita cultivated land (1921–1961)

Census year	Population* (millions)	Cultivated Land per Capita (hectares)
1921	248	0·44
1921	276	0·42
1941	313	0·38
1951	357	0·34
1961	438	0·30

*Adjusted as per territory of India today

At present, there seems to be little possibility of bringing additional land under cultivation. To offset the shortage of productive land, the land now in use must be made to produce more. Double-cropping on areas under irrigation and a deliberate concentration on the production of high-calorie crops and greater yield per acre represent essential goals toward which progress is urgently needed. This

requires measures to provide irrigation, application of manures and fertilisers, use of better seeds, adequate plant protection, soil conservation, and suitable cropping patterns.

Measures to increase yield per hectare were emphasised in three Five-Year Plans. Though over-all achievement has been fairly good, the goals are far from being reached. In the 10 years from 1950-1951 to 1960-1961, agricultural production increased on an average of about 3·5 per cent a year. Although this was a significantly faster rise than that of population 2·15 per cent), more than half of this increased production was, unfortunately, due to an increased use of land (limited in extent) that is marginally cultivable and previously idle.

Soil Surveys

The pressure of population and the emergency needs of subsistence farming have sometimes forced farmers to grow crops on land which is not the best-suited for the crops. For the purposes of planned production for food and the best utilisation of soil resources, it is imperative that the suitability of the soil for a particular crop be carefully determined. Reconnaissance and detailed soil surveys in selected regions, especially those intensively cropped, should constitute the basis of land use.

In regions of settled agriculture, experience has already provided useful information on the suitablity of the soil for the crops grown. Work on soil surveys has been done, but in terms of the total 326·3 million hectares concerned, they cover only a small portion, particularly in respect to detailed surveys. The All-India Soil Survey Organisation has, up to the end of the Third Five Year Plan, covered 10·44 million hectares including reconnaissance survey of 7·02 million hectares and detailed survey of 3·42 million hectares. State Governments have conducted a few detailed but mostly reconnaissance surveys of about 10·0 million hectares and a scheme is under way in the States for a survey and localisation of wastelands in blocks of about 2 or more hectares. The Central Water and Power Commission has, under various irrigation projects, carried out (up to June, 1961) a reconnaissance survey of about 10 million hectares. Important as these surveys are, they still leave much to be accomplished. Soil Surveys and the preparation of land-use maps of critical areas, particularly in the catchment areas of River Valley Projects, need to be intensified. It is urgent that soil conservation measures in these catchment areas be given immediate attention because the large investment in these projects may otherwise be wasted by the rapid silting of the reservoirs.

The main problem in India is to increase yield per hectare. For this, detailed knowledge of the soils of each plot is essential. While this is essential for farms of all dimensions, this is more important for small units of cultivation. Depending on the size of the cultivation unit it will be necessary to draw soil map of the area in the scale 1 : 3960 or 1 : 1980 or even larger scale. Such a map should include the soil characteristics in respect of surface and sub-soil and should be accompanied by definite plan of using the farm unit which should be drawn up in consultation with the farmer. The Plan should contain all round package programme including practices like use of high yielding varieties of seed which can stand heavy manuring, addition of adequate quantities of manures and fertilisers, irrigation where needed, adding gypsum to alkali soils, liming of acid soils, and adoption of soil and water conservation measures.

Land Use Planning

In land use planning there are three cardinal principles : firstly it should be possible to find the optimum use in the national interest of any given land : secondly in a large number of cases, multiple cropping of land is both desirable and possible and thirdly there should be complete elimination of wastelands, as there is a possible use of every bit of land in a crowded country.

Production in the small units of cultivation can be stepped up not only by putting all factors of production in a compact manner which every developed agricultural programme would take into account, such as better seed, proper fertiliser use, use of soil amendments, use of plant protection measures, etc. but it should also take into account proper land use. In many areas in India even though a particular crop is grown every extensively and that has been the practice over centuries, there is a possibility of changing the crop pattern which is more adaptable from the standpoint of climate and soil and bring about much better return to the farmer with the same amount of enterprise and investment. For example, in the plateau region of Chhotanagpur in Bihar where upland paddy is grown very extensively along with some small millets and the yield is generally very poor, with improved varieties of upland paddy, use of fertilisers and plant protection measures the yields can be raised twice or even three times, but if the crop of paddy or small millets be replacad by a food crop which has a potentiality of high yields, then the farmers are definitely to get much more income than what they can get fr m paddy cultivation on these lands. For this a careful study of the interaction between soil, water management and crop rotation is desirable. Such a study can be profitably undertaken in the Government seed farms particularly in those which have been newly opened. The question of undertaking such a study in some of these representative farms without vitally affecting their seed production programme may be given consideration. The information thus available will be of practical use in formulating further programme in respect of small units of cultivation for getting the best return.

Soil Conservation

About 81 million hectares of the total area of India requires protection through soil conservation measures. That such measures represents an urgent national programme was recognised in the First Five Year Plan. The Second Five Year Plan covered soil conservation measures for 0·8 million hectares of agricultural land. During the Third Five Year Plan about 4·0 million hectares have been covered by soil conservation measures.

Wastelands

Wastelands for the extension of cultivation for food crops, pastures, or forestry totals about 50 million hectares (127·4 million acres). The Wasteland Survey and Reclamation Committee of the Ministry of Food and Agriculture has estimated that nearly 0·8 million hectares of wasteland is available, in blocks of about 100 hectares or more, for cultivation, and has submitted useful reports to the individual States for utilisation of such lands in their States. Quick action should be taken to implement the recommendations of these reports, which were made in coordination with the Government plan for the settlement of landless labourers.

In view of our effort to step up crop production, the reclamation of acid, alkali, and saline soils is urgently necessary. In this country, not much attention was earlier given to the problem of liming of acid soil. The beneficial effects of treating alkaline soils with gypsum have been recognised here, but so far no

sizeable area of alkali soil has been reclaimed and work in this area needs intensification on a national scale. In a study of the Wastelands of India, the Committee on Natural Resources of the Planning Commission issued a very useful report that includes valuable statistical information and practical reclamation recommendations for saline, alkali and water-logged soils. This report can lead to the formation of policy measures for the reclamation of such lands in the Fourth Five Year and subsequent Plans.

Although wastelands which may be reclaimed economically are important potential sources of increased national food and wealth, higher yields per hectare from better soil management and improvement of inherent soil fertility through use of organic manures and green manures need attention. Extensive trials made in different parts of the country have shown that a much higher level of production can be obtained by (*a*) green manuring over 49 million hectares in areas where the rainfall exceeds 76 mm. or where there is assured irrigation and (*b*) using compost in another 60·7 million hectares in places where the rainfall is below 51 cm*.

Field Fertiliser Experiments

In 1944, the Indian Council of Agricultural Research invited A. B. Stewart of The Macaulay Institute of Soil Research (Aderdeen, Scotland) to review our soil fertility investigations. In 1947, after an extended tour of India, Stewart wrote an extensive, detailed report that included valuable suggustions which during the following years, vitally affected both the philosophy and the practice of fertiliser experimentation in this country. He particularly stressed the need for simple fertiliser trials on cultivators' fields, and for complex experiments at carefully selected centres of different agro-climatic regions of the country. Prompted by Stewart's suggestions, in 1949 the I. C. A. R. initiated a scheme under which a series of 3- or 4- plot trials were conducted on cultivators' fields in seven districts in different States. This work continued for three years and was followed by a plan known as the Soil Fertility and Fertiliser Use Project 1953-56 which was sponsored by the Government of India in cooperation with the Technical Cooperative Mission, the United States, and the State Governments. Under this project simple fertiliser trials were conducted on cultivators' fields (mostly on paddy and wheat) at the 22 Community Project Centres located in different parts of the country. The results obtained on paddy and wheat have been published by the I. C. A. R. as research reports.

The experiments conducted under the T. C. M. project provided very valuable information on crop response to fertilisers on cultivators' fields, but, in view of the size of the entire country, their scope was rather limited. In order to have comprehensive information for various soil types on the responses of different field crops to different fertilisation, a Coordinated Agronomic Experiment Scheme was included in the Second Five Year Plan and continued in the third Five Year Plan. This scheme consists of two parts : the coordinated Scheme of Simple Fertiliser Trials on Cultivators' Fields, and the Model Agronomic Experiments Scheme. The work is being conducted jointly by the Indian Agricultural Research Institute and the Institute of Agricultural Research Statistics with the Cooperation of the State Departments of Agriculture.

The objective of the Scheme of the simple fertiliser trials is to estimate the responses to nitrogen, phosphorus, and potash for the important field crops in

*M. S. Sivaraman, Greater use of organic manure can raise farm yields, Capital (Supplement), December 20, 1962.

different parts of India, and to study the variation in response from one region to the other, in order to provide farmers which general fertiliser recommendations. The relative efficiency of different nitrogenous and phosphatic fertilisers is also being studied. Three types of simple trials were planned, and by the end of the Second Five Year Plan experimental work was in progress in 143 districts. In the final year of the third Plan the work was in progress in 170 districts. About 20,000 experiments were conducted in 1965–66.

From the intensive fertiliser-use programme the following conclusions were drawn :

(*a*) The universal response of different crops to nitrogen application was confirmed.

(*b*) Crop response to various forms of nitrogenous fertilisers, when applied at the same dose, not vary greatly.

(*c*) Response to phosphatic fertilisation is profitable for about 60 per cent of the soil of India.

(*d*) In the majority of the trials at the low rate of application tried, the responses were more or less additive.

(*e*) In certain areas and on certain crops, response to potash is a local response.

(*f*) Investigation on the interaction of fertiliser responses with agronomic practices showed that factors such as irrigation and early planting of crop had a positive interaction with the fertiliser.

Loss of Soil Nutrients

It has been estimated that crops in India remove from the soil annually about 4·2 million tonnes of N and 2·1 million tonnes of phosphoric acid (as P_2O_5), a good part of all of which has to be replenished through the application of manures and fertilisers. The extensive, use of nitrogenous and phosphatic fertilisers, however, may be accompanied by adverse effects, for example, such residual effects as the soil acidity and depletion of other nutrients from the soil by crop removal. Thus, in the use of fertilisers, a close watch must be maintained in order to diagnose specific nutrient deficiencies in time to take remedial measures. Optimum productivity of cultivated lands can only be maintained to the extent that such nutrient deficiencies are overcome.

Application of fertilisers

While organic manure is essential for maintaining soil fertility by providing raw material for humus formation, stimulating biological action, and improving the structure of the soil and its biological activity, it cannot, by itself, provide all the necessary plant nutrients. The addition of mineral fertilisers according to the requirements of the soil and the crop is, therefore, essential. It has been estimated that the addition of a tonne of ammonium nitrate increases the yield of food grains by 2 tonnes.

As a result of fertiliser experiments and trials carried out in cultivators' fields, the State Governments have formulated manurial recommendations for the important crops in their individual States.

Soil testing has proved a very useful tool in the hands of soil scientists and agronomists for assessing the fertility of soils for guiding proper fertiliser use and thus eliminating guess work in supplying fertilisers to the crops.

Under Indo-U. S. Project on Soil Fertility and Fertiliser Use, a start has been made by setting up 24 soil testing service laboratories at different locations. Besides the above, the State Government of Bihar has established three new laboratories of their own which are located at Ranchi, Patna and Pusa. Similarly the State Government of erstwhile Punjab has established one more soil testing laboratory at Palampur and another at the Government Agricultural College, Hissar. These laboratories have been equipped so as to analyse 10,000 soil samples a year. Recently the laboratories at Ludhiana, New Delhi, Bangalore and Sambalpur have been remodelled with the help of U. S. aid and every one of these laboratories is capable of analysing 30,000 samples a year. Plans to set up more soil testing laboratories in the intensive agricultural areas are underway. There is proposal to strengthen the well equipped centres in the various soil climatic regions for working on the soil test and crop correlation work more intensively. These laboratories have been rendering free advisory services to the farmers. Apart from this objective of giving advice on fertilisers and soil amendments (if needed) to be used for getting most profitable and increased crop yields, soil tests provide data of great value in several other ways. The preparation of soil fertility maps and soil test summaries has been of help to planners, fertiliser industry and extension workers in planning for fertiliser industry and fertiliser production, distribution and consumption in the country. The All India soil test summaries prepared up to 1964 showed that about 52% of soils were low, 30% medium and 18% high with respect to available phosphorus; 31% of soils were low, 39% medium and 30% high with respect to available potassium; and 52% of soils were low, 32% medium and 16% high with respect to nitrogen.

Need for nitrogenous fertilisers is almost universal. Similarly, acidic or alkaline soils require lime practices or application of gypsum respectively. Not much attention was given earlier to the problem of liming the soils in this country and the need for taking suitable measures for these problem soils is very urgent for stepping up crop production.

Soil tests undoubtedly play an important role towards production through encouraging balanced and optimum use of fertilisers. The soil test data when superimposed on other agronomic data on soil type basis, would prove of great value of deciding the fertiliser mixture ratios which can be recommended to the farmers for different crops.

Progress in Land Productivity

From 1957–1958 to 1965-66 rice and wheat yields per hectare gradually increased (Table 3), but since 1960–1961 these yields have remained almost unchanged. The period of increased yield was apparently due to the planting of better varieties and, to some extent, the use of fertilisers and manures. Yield of rice per unit area, however, varies widely in different parts of the country, ranging from about 4·48 quintals per hectare (400 pounds per acre) to as high as 33·60 quintals per hectare (3000 pounds per acre), depending on location, water availabillty, and management.

TABLE 3*

Average yields of principal cereals

Time period	Rice: Pounds per acre	Rice: Quintals per hectare	Wheat: Pounds per acre	Wheat: Quintals per hectare
1949–50	688	7·70	584	6·54
1950–51	596	6·67	592	6·63
1951–52	637	7·13	582	6·52
1952–53	682	7·63	681	7·63
1953–54	805	9·02	670	7·50
1954–55	731	8·19	717	8·03
1955–56	780	8·74	632	7·08
1956–57	803	8·99	620	6·94
1957–58	702	7·86	592	6·63
1958–59	835	9·35	703	7·87
1959–60	837	9·37	694	7·77
1960–61	909	10·18	756	8·57
1961–62	906	10·16	794	8·90
1962–63	815	9·14	707	7·93
1963–64	918	10·29	651	7·30
1964–65	958	10·74	810	9·09
1965–66	778	8·72	746	8·36

Given the proper conditions, therefore, yield per unit area of Indian soils can be increased. In addition to use of improved seeds, and measures against attacks from pests and diseases, the major areas of soil management to consider are :

(*a*) Increased supply of water for irrigation.
(*b*) Adequate supply to soil of organic matter, including green manuring.
(*c*) Adoption of a suitable plan of crop rotation.
(*d*) Application of fertilisers.
(*e*) Drainage and bunding.
(*f*) Stimulation of farmer incentive.

Water for irrigation

At the end of the Third Five-year Plan the estimated net area is 35·9 million hectares. Very close scrutiny is needed to consolidate the use of the increased irrigation potential already created, which would involve making drains, preparing and levelling the land, and acquainting the farmers with methods of applying irrigation water in relation to the soil and crop to be irrigated.

Adequate organic matter

Indian soils are poor in organic matter. It has been proved beyond doubt that the continued use of bulky organic manures, including green manures, helps to build up soil fertility. It has also been established that, by increase in the inherent soil fertility through the application of bulky organic manures, crop yields can go beyond the existing yardsticks of increased production to various other inputs in agriculture. Since organic manures also help to conserve more moisture in the field, their application is of great importance, as 75 per cent of the cultivated area in India will continue to depend upon the uncertain monsoon rains. In fact, one of the main reasons why yield per hectare of Indian soil had decreased is that manuring has come to be practised less intensively than in the past; the

*Reference : Statistical abstract, published by the Central Statistical Organisation; and Estimates of Area and Yield of Principal Crops in India (Ministry of Food and Agriculture and the Indian Trade Journal).

population increase has expanded cultivation to include lands and areas of forest growth, which has affected the quantity of farmyard manure, green manure, and compost available for the cultivated lands The agriculture practices in Madras have shown that, by growing suitable plants and shrubs, the required organic manure may be produced within the cultivated land without affecting normal cultivation; green-manuring the fields with the vegetation produced would yield about 0·25 tonnes of extra food grain per hectare. It is generally held that application of 12·5 tonnes of compost per hectare yields about 187·5 to 280 kg. (5 to 7·5 mds.) of extra food grain.

The work of N. R. Dhar on the utilisation of basic slag along with organic matter for improvement of soil fertility has established that this material can be widely used in the country, particularly in areas near about the steel plants for increased crop production.

A suitable plan of crop rotation

Suitable crop rotation and crop planning would be a practical way of maintaining and improving soil fertility and increasing farm production, and, coupled with the use of manures and fertilisers, a great improvement of soil fertility may be expected to result from a judicious use of the practice. In addition to improving soil fertility and controlling erosion, the inclusion of legumes and also of fodder in crop rotation, the usefulness of which is established, would help to place the animal husbandry industry on a firm footing.

Drainage and bunding

Drainage of soils, particularly for irrigated areas, should receive greater attention. In many location swamps and water-logged areas could be reclaimed by drainage, although such land should carefully be surveyed since some of it could be better developed either as fisheries or for purposes of recreation or the preservation of wild life.

In some areas where a single crop of paddy is taken in a year, the question of drainage seems to deserve close attention. In extensive areas in West Bengal, Assam, Orissa, and other States, topography and drainage determine whether one, two, or three crops will be grown, but drainage of the comparatively low-lying areas that under existing conditions yield only one crop is likely to make possible a second crop.

In areas where either the rainfall is deficient or irrigation is not available, conservation of moisture by contour bunding in sloping areas assumes a great importance. Even in areas where either the rainfall is moderate, the conservation of moisture by bunding is of great importance for crops grown after the monsoon. The vagaries of weather demand particular attention to the conservation of moisture. A number of schemes to ascertain the best ways of conserving moisture are under way in different parts of the country, and in certain areas, have yielded promising results. In Madhya Pradesh, Andhra Pradesh and Maharashtra, Mysore, and Madras States such plans have been initiated on a large scale. Generally it is held that contour bunding leads to an increased production of about 25 per cent.

Stimulation of farmer incentives

Agricultural production depends on soil fertility, soil management, and the financial resources of the farmers. To fight the battle for a shift in the farmer's attitude from one of farming for subsistence to one of farming for profit the farmer must be provided with technical knowledge. But it is even more necessary to stimulate the farmer to produce more by assuring him of monetary rewards for his investment and enterprise on a scale which does not compare unfavourably with other forms of productive work, for example those he would find in industry;

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Restoration of Soil Fertility

By

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Systematic soil depletion started with the beginning of deforestation and destruction of natural vegetation and the growing of high yielding selected strains of plants was aggravated by intensive agriculture unaided by adequate safeguards to maintain soils at high state of fertility through proper cultural practices. Soils of high productivity only could increase acre-yields. High acre-yields coupled with healthy after-effect on the soil leading to sustained crop production remains the unquestioned need of our soils. Considering the Indian conditions of agriculture with its manifold problems, any system that fulfils the need and be accessible within the limited resources of the farmer ensuring no pitfalls should be most profitable to the maintenance of soil fertility. Skilful use of legumes as cover crops in rotations or as associate crops have the potency to enrich soils admirably in organic constituents as well as nitrogen.

In nature, plants appear in harmony with the soil and climatic conditions, and at the end of their life return the organic matter elaborated within their body to the soil. With the introduction of clean cultivation this aspect of natural restorative agency was eliminated for most areas although green manuring practiced by Indian Farmers on soils of low fertility represents the value of plants in maintenance of soil fertility. The death and decay of these plants provided organic matter to the soil while others in the vicinity were still growing and forming seeds for next generation. This formed the basis of rotation of crops, yet another invaluable practice. With the set conditions of habit and enormous increase in global population, however, it would be unthinkable to return to the past civilization of nomadic era and allow the vegetation a free hand to grow and restore the lost fertility of the soil.

With advent of intensive agriculture, farming has been associated with the western methods of fertilizer application whose quick returns provided the vision of rich awards from soil exploitation. These methods copied from the temperate climes without any experimental basis showed the futility of their indiscriminate application to semi-arid, tropical and sub-tropical conditions of the Indian soil on any large scale. Mechanization of agriculture had further disadvantage of unfavourably disturbing the microbiological population under the hot sun, disturbing the soil-water and soil-nitrogen balance.

The Indian farmer realized the value of the ways of the nature, earlier than any other country, and practiced polyculture as opposed to the general practice of monoculture of the West. The confusion created between the use of age-long practice of cropping and indiscriminate use of concentrated fertilizers has obviously given a setback and an element of uncertainty to crop production and crop yields. Records of crop yields in Uttar Pradesh from the time of Akbar down to the period prior to introduction of the use of fertilizers showed

that the nitrogen status of Indian soils had reached more or less a rough condition of equillibrium when the annual gains and losses were believed to almost balance. Recent crop-weather statistics suggest a definite stepping down of both the acre and total yields during the past sixty years. It thus becomes essential to search for the scientific principles to base our farming practices on sound footing; there is need of growing legumes that are less exacting in their demands alternatively or in association with non-legume since, of the many factors that limit crop production in India, the most important are soil-water and soil-nitrogen.

Nitrogen, the balance wheel of nature, may rightly be recognised as the master key to agriculture under Indian conditions. The supply of available nitrogen is indispensable for maintenance and improvement of soil fertility and also adequate growth of plants leading to increased yields of superior quality. Nitrogen is the most expensive fertilizer element and one easily lost from soil. The most effective cultural practice that seems to offset nitrogen losses is the growing of crops that utilize the available free nitrogen, in the growth processes, arrest and convert it to forms which when returned to the soil constitute potential and more stable source of nitrogen, less subject to leaching. The practical method for nitrogen recuperation of soil is skilful use of cultural practice *viz.*, fallowing, green-manuring, legume rotation and mixed cropping.

No single crop husbandry practice could play such a vital role in India in rehabilitating soil conditions and maintaining crop producing capacity of the soils, as mixed culture. Although mixed culture has been in *vogue*, in India, for a long period, little thought has been given to the impact of this practice for the maintenance of soil fertility. A survey of the existing practice of mixed culture in India shows that large number of plant associations have been tried. Crops like paddy, bajra, finger millet, jowar, barley, wheat, maize, pigeon pea, cotton, Indian millet and groundnut have 16, 19, 19, 25, 11, 9, 22, 17, 18, 21 and 17 associate crops, respectively, to their credit (1).

Besides these, sugarcane, coriander, onion, radish, pigeon pea and leafy vegetables and other crop mixtures are raised together in different parts of the country. Growing together of beet, mustard, radish and cauliflower encourages the incidence of white rust. Sandal and colocassia when grown with betel nut are infested with *Kolaroga* disease. Potatoes, chillies, brinjal and tomato in association, promote chances of wilt or ring disease. Similarly growing of potato, tomato, cowpea and groundnut gives greater chances of incidence of hypochonas disease. Chillies, brinjal, castor bean, garlic, cucurbits in association, increase mildew. Similarly, growing cotton with kidney bean or with jowar encourages root rot. Looking to these examples of polyculture, we find that there are may diverse types of associations found among crop plants; not all of these crop associations are valuable either for yields or soil fertility.

Most prevelant crop associations in the state of Uttar Pradesh are *gochana* (wheat+gram), *gojai* (wheat+barley) in the *Rabi* although many more associations with pigeon pea as legume are common during the *Kharif* season. In order to increase or conserve soil fertility and obtain larger yields this inexpensive practice of growing two or more crops in association may be employed tactfully. Proper utilization of the land under the plough needs the determination of most favourable plant associations and also the optimum seed rate proportionality between the associate crops.

In order to evaluate the effect of interaction of crops growing together, that between wheat, gram and mustard was studied (2). Seven crop combinations *viz.*, wheat (W), gram (G), mustard (M), wheat+gram (WG), mustard+gram (MG), wheat+mustard (WM) and wheat+gram+mustard (WGM) were tried. Seed rate proportionality among associates was maintained as W : G : : 4 : 1, W : M : : 10 : 1, G : M : : 6 : 1, W : G : M : : 20 : 5 : 1. On the basis of prevelant seed rates the crops were raised with the quantity of seed as W=50, G=30, M=5 lbs. per acre. Seed rate for mixtures were WG=32+8, WM=25+2·5, GM=15+2·5 and WGM=30+7·5+1·5 lbs. per acre.

With the introduction of companion crop the growth of components assumed special significance. Association of a legume increased the growth, development and dry matter production of the non legume companion. The increase in the area of wheat leaves in wheat-gram mixture combination (Table 1) suggested the benefit to be due to the ready availability of nitrogen.

TABLE 1

Effect of mixed cropping on wheat plant (Leaf area, sq. cm/plant)

Crop Associations	Age in days					
	40	60	80	100	120	140
W	65·50	105·60	115·73	145·34	129·69	54·73
WG	69·34	118·34	132·51	161·23	138·31	61·85
WM	63·11	104·29	109·43	138·80	124·17	50·03
WGM	67·22	116·52	121·90	152·63	130·57	55·32

S. E. = 1·60 C. D. = 5·82

Nodulation was enhanced numerically and significantly so, in gram roots, when grown with wheat alone or with wheat + mustard (Table 2).

TABLE 2

Effect of mixed cropping on nodulation of legume companion

Nodule character	Crop associations	40	60	80	100	120	140
Count/plant	G	9·50	18·53	36·84	40·33	16·96	14·98
	GW	12·02	29·46	48·34	53·18	27·37	20·14
	GM	11·19	20·43	40·42	42·07	19·63	16·31
	GWM	10·91	22·52	42·63	44·51	22·48	18·81
			S. E. = 0·7754		C. D. = 2·336		
Dry weight mg./plant	G	23·75	32·50	61·25	46·15	32·60	30·50
	GW	42·45	73·12	91·37	59·45	44·02	40·95
	GM	36·35	37·37	61·75	47·90	33·30	31·37
	GWM	39·65	56·25	74·85	52·15	38·40	32·37

S. E. = 2·547 C. D. = 7·675

With the presence of cereal in association with legume the size, number and weight of nodules increased, but with the introduction of mustard (WGM partnership) the growth, development and functioning of nodules was retarded. The crop mixture (WG) increased the protein value of cereal as well as of legume seed (Table 3).

TABLE 3

Effect of crop association on protein value of seed (%)

Replicates	Wheat Crop associations W	WG	WM	WGM	Gram Crop associations G	GW	GM	GWM
I	12·210	13·164	12·026	12·804	18·514	18·670	18·648	18·619
II	12·214	13·160	12·000	12·802	18·506	18·676	18·650	18·620
III	12·209	13·162	12·027	12·810	18·512	18·674	18·643	18·621
IV	12·217	13·164	12·005	12·800	18·515	18·677	18·647	18·626
	S.E. = 0·00002		C.D. = 0·141		S.E. = 0·008		C.D. = 0·0256	

That the cereal (wheat) grew better in association with legume (gram) while the latter did not stand to lose was borne out by these investigations. It did not hold true with mustard-gram or wheat-mustard-gram associations. This characteristic nature of mutual benefit in associated culture was traced to be due to increased ability of gram to fix nitrogen and also excrete to the benefit of non-legume companion (4) and also soil (Fig. 1).

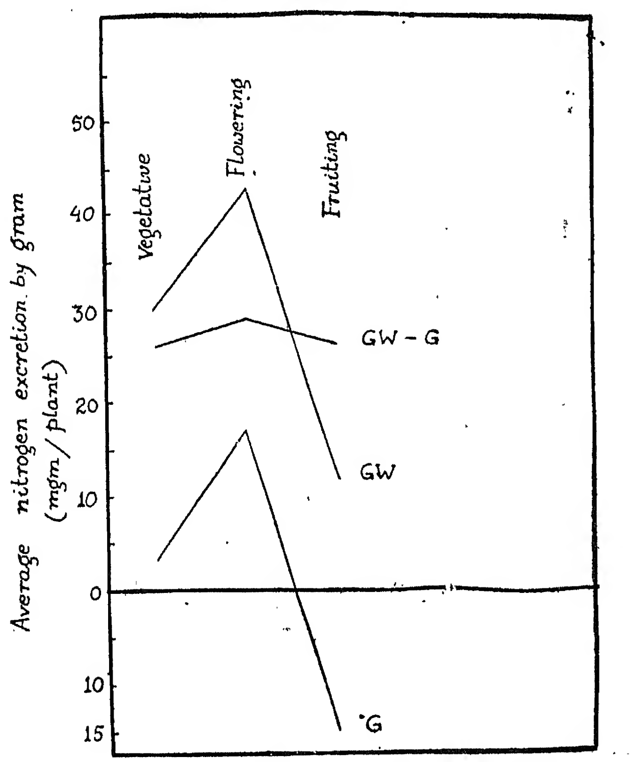
The shift in straw : grain ratio of gram from 1 : 2 for single culture to 2 : 1 in WGM association (Table 4) also supported the above contention (2).

TABLE 4

Grain and straw yield of wheat, gram and mustard grown singly and mixed
(mds/acre)

	Crop associations W	G	M	WG	GM	WM	WGM
Wheat (grain)	16·40	–	–	15·42	–	11·97	12·75
(straw)	28·58	–	–	35·67	–	22·01	25·64
Total	44·98	–	–	51·09	–	33·98	38·39
Grain (grain)	–	14·57	–	12·81	13·14	–	8·68
(straw)	–	7·19	–	10·72	9·49	–	16·60
Total	–	21·76	–	23·53	22·63	–	25·28
Mustard (grain)	–	–	8·64	–	6·13	6·82	5·79
(straw)	–	–	10·27	–	15·45	8·87	9·78
Total	–	–	18·91	–	19·58	15·69	15·57

In respect of yield two groups of associations were noticed. The first, principally composed of wheat and gram, with definite superiority over the other group having mustard as associate. Wheat grown singly produced maximum while mustard the minimum. Between these two limits lay rest of treatment combinations. While WG association yielded consistently more that due to MG was the lowest, showing the deleterious effect of mustard as associate.



G ≡ Gram , GW ≡ Gram + wheat

Fig 1. The effect of single (Gram) and mixed culture (Gram-wheat) on excretion of nitrogen by *Cicer arietinum*.

Produce obtained from an unit area may be roughly taken to be a fair index of the inherent capacity of the soil to yield. The wheat-gram association thus enhances the crop producing capacity of the soil. It thus seemed economically sound to grow wheat and gram together but not mustard and gram. Similar findings may come to the forefront with other crop associations also. Considering the overall effect of crop association on the legume companion it was revealed that there was increased nodulation, more protein and higher dry matter production of both tops and roots (Table 5).

TABLE 5

Overall effect of crop associations (% Increase or decrease over control)

Characters	GW	GWM	GM
Nodule number	+ 39·10	+ 18·02	+ 9·40
Nodule weight	+ 54·96	+ 29·53	+ 9·39
Dry matter accumulation (tops)	+ 63·98	+221·76	+ 44·82
Dry matter accumulation (roots)	+180·03	+491·07	+109·10
Seed protein	+ 0·86	+ 0·59	+ 0·70

The effect of cereal companion on nodular mass as well as excretion, transfer and fixation of nitrogen by the legume was studied in another series of investigations under relatively controlled pot trials (4). Nodular mass, nitrogen excretion, and nitrogen fixation were of higher order in gram, grown mixed with wheat. Nodular activity could be gauged by excretion or fixation of nitrogen (Table 6).

TABLE 6

The overall effect of wheat-gram association on companion legume

Characters	% increase or decrease
Nodular mass	+ 4·34
Nitrogen excretion	+119·28
Combined transfer[1]	+74·90
Real fixation[2]	+73·84

1. *Combined transfer* refers to the nitrogen content of the host plant exclusive of that in the nodules *plus* the nitrogen excreted into the medium. In mixed cultures the value of the excreted nitrogen also includes the amount of nitrogen transferred to the companion crop.

2. *Real Fixation* refers to the nitrogen content of the host plant in the nodules *plus* the amount excreted into the medium. In associated cultures the value of excreted nitrogen also includes the amount of nitrogen transferred to the companion crop.

These findings confirm the earlier stand that mixed cropping between a legume and non-legume encourages greater nitrogen fixation in the soil.

Profitable crop associations, once determined, could be made more so by adjusting the seed rate proportionality between the associate crops which is a variant of a high degree. It is quite common to find variations ranging 2 to 225 times in the existing seed rates practiced for different crop mixture in the country (1). We may have some common examples (Table 7).

TABLE 7

Prevelant range of seed rate proportionality between some associated crops

Associate crops	Seed rate ratios	Variations (Times)
Bajra : cotton	1 : 1/4 to 1 : 1/2	2
Bajra : til (*Sesamum*)	1 : 1/3 to 1 : 1/51	17
Jowar : water melon	1 : 1/2 to 1 : 1/50	25
Cotton : finger millet	1 : 1/8 to 1 : 6	48
Barley : lentil	1 : 1 to 1 : 1/99	99
Cotton : chillies	1 : 1 to 7 : 1/32	224

The seed rate proportionality in wheat and gram has, stood in variance and wide apart from one State to another in the country. The seed rate proportionality (by weight) practiced between wheat and gram are W ; G : : 1 : 1. 2 : 1, 10 : 1 in Hyderabad ; 1 : 1, 1 : 1·5, 1 : 2 in Bengal; 1 : 1, 2 : 1, 3 : 1, 4 : 1 in the Punjab ; 1 : 1, 2 : 1 in Assam ; 4 : 3 in Bhopal ; 1 : 4 in Bombay and from 1 : 1 to 6 : 1 in Uttar Pradesh. With such wide fluctuation in the seed rate proportionality of the mixture, it is not possible to know precisely as to which ratio would be optimum for crop yield and maximum restoration of soil fertility.

A field study (3) was undertaken to evaluate the influence of seed rate proportionality in legume – cereal combination. Between wheat and gram the seed rate ratios were 5 : 1, 4 : 1, 3 : 1, 2 : 1, 1 : 1, 1 : 2, 1 : 3, 1 : 4 and 1 : 5. Each unit was equivalent to 8 lbs of seed/acre.

Analysis of data revealed that maximum combined yield of grain and straw of wheat and gram singly and also collectively was obtained when seed rate proportionality was maintained as W : G : : 4 : 1. The yield obtained was 33·14 mds/acre for wheat and 28·53 mds/acre for gram.

In wheat–gram mixtures, wheat plants served as perfect index of the excretion of nitrogen by the companion gram for maximum grains. For highest return companion crops became a function of their seed rate which determined the yield of each of these and also the overall total produce. The controlling influence of crop associations as well as seed rate proportionality in the maintenance of soil fertility thus became obvious.

Agricultural crops are not to be grown in association solely on the basis of their ability to withstand the competition but also from the point of view of relative seed rate that would operate favourably upon the associates to the advantage of yield and also soil fertility. Manuring or fertilization may be considered inevitable but at times it becomes difficult to assess or even supply the needs of the soil through additives. Evolution of cropping system which may replenish soil-nitrogen and conserve soil-water while high yielding strains continue to be reaped, may be done by growing of two or more crops in proper seed rate ratios for maximum return.

Of the many advantages of crop–rotation those by way of higher yield and increase in productivity of the soil are most significant. Tobacco, castor and legumes with deep root system may be rotated with barley, wheat, maize having shallow root systems for maintaining the fertility status of the soil.

Alternate growing of such crops that need intensive working of the soil *viz.*, groundnut, potato, onion, sweet potato etc. help in making the soil soft, malleable and porous and thereby increase the productivity of the soil in many ways.

The nitrogenous fertilizers like sulphate of ammonia make the soils acid and create soil sickness by increasing the availability of aluminium, manganese etc. This leads to disorders of soybean, tobacco, potato, *moong* etc. Application of sulphate of potash to soil increases the intake of boron in turnip and tomato leading to losses.

The crops like beet, knol-khol, cauliflower, potato, lucerne tobacco, carrot, apple, lemon etc. suffer from deficiency of boron and therefore their continuous culture should be avoided. Oats, potato, tomoto, cucumber, pea, bean, sugarcane etc. need larger supply of manganese ; copper deficiencies are specially harmful for pulses, oat and many cereals. Zinc must be available to grape and maize and calcium to tomato, oat and cauliflower for proper growth and development. Such and other difficulties associated with soils cannot be solved by application of fertilizers due to obvious reasons.

In formulating the scheme of rotations the needs of crops for microelement should also be borne in mind. Crops like tomato, soybean and beet are sensitive to boron ; tobacco, potato, *moong*, pea, soybean to manganese ; paddy to copper ; *Raphanus*, linseed, barley, to molybdenum, and, maize, soybean to aluminium. Soils with preponderance of these minor elements should be as far as possible not cropped with such crops which suffer from their toxicity. The same holds good for areas deficient in minor elements for crops that need larger supplies.

Judicious crops associations with optimum seed rate proportionality, green manuring, and scientific crop rotations may thus be encouraged to increase the fertility of soils.

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Maintenance of Soil fertility with lime, legumes, slags and microbes

By

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Tropical soils are generally of low fertility compared to the soils of temperate regions. This is primarily due to the poor organic matter and consequently low nitrogen contents of these soils. The nitrogen content of Indian soils, on an average, may be reckoned to be about one-third of the nitrogen content of the soils of European and North American countries. Therefore, much of our endeavour to step up food production depends on the use of nitrogenous manures and fertilizers. Our soils are also very poor in phosphate and the need for phosphatic fertilizers has become as important as that for nitrogenous fertilizers, today.

Our farmers are gradually realising the need for fertilizers and demand for them is growing. Already the demand has exceeded the supply and the production has lagged behind. It is now necessary to establish Sindri type of fertilizer factories in large numbers In the Fourth Plan period the production of fertilizers will be much greater than what it is at present but the demand will probably grow even faster. Thus the shortage of fertilizers, as prevalent in the country now, is likely to continue.

The most important indegenous manure available in millions of tons, in this country, is the cow dung. It is an organic manure containing not only nitrogen but also phosphates, potash and other plant nutrients. If well rotten cow dung is used as a manure, on equivalent nitrogen basis, needs of many other nutrients are also met to a great extent. Further, improvement of physical and biological condition of the soil are additional advantages that may be derived from the use of cow dung.

Unfortunately, about three-fourth of the dung excreted by our cattle in this country is not available as manures. Most of it is used as fuel. India has one-third of World's cattle population. The output of dung should also be proportionately, one-third of the World production. If we could use the entire amount as manure much of our misery in facing fertilizers shortage could have been eliminated.

The effect of bulky organic manures including green manuring on crop yield studied in a very large number of field experiments all over the State of Bihar has been generally found to be inferior to that of N P K fertilizers. A typical sample of these results is shown in Table 1. Continuous use of compost of F. Y. M. may however build up soil fertility level to yield at par or higher than the fertilizers. A continuous use of ammonium-sulphate in a red loam acid soil (Kanke, Ranchi) in a maize-wheat rotation for 10 years brought about a deterioration to the extent that the yield level dropped to that of the no-manure plots (Table 2). The use of

phosphate in combination with nitrogen or F. Y. M. at equivalent N basis prevented such deterioration. These results therefore suggest, amongst other things, the importance of phosphorus content of bulky manures in the maintenance of soil fertility.

TABLE 1

Effect of organic manures on the grain yield of wheat (Neutral loamy soil)

Manure added*	Average yield 1960–63	Org. C., mg., % Walkley and Black 1962-63	
		Initial	Post haıvast
None	780	581	624
F. Y. M.	966		714
Compost	1033		714
Ammonium Sulphate	1312		692
C. D. at 5%	154		

*Manure and fertilizer added to supply 40 lbs. N per acre.

TABLE 2

Effect of organic manures and fertilizers on grain yield in an acid red loam during the 10th year of continuous application

Manure added*	Yield lbs./acre		Org. C., mg.% (post-harvest)	
	Maize	Wheat	Maize	Wheat
None	328	607	0·570	0·600
Ammonium Sulphate (N)	672	418	0·600	0·585
F. Y. M.	2591	1443	0·765	0·885
N + P (Superphosphate)	2091	1607	0·630	0·675
C. D. at 5%	1246	369		

*F. Y. M. and ammonium sulphate added to supply 40 lbs. N superphosphate at 40 lbs. P_2O_5 per acre.

There are other means of increasing the productivity of soils. The aim of this paper is to emphasise the importance of some of them that may alleviate the difficultices caused by fertilizer shortage on one hand and colossal waste of cowdung as fuel, on the other hand.

1. Green Manures

The use of green manure in building up soil fertility has been widely advocated in this country since long. Of late, a question is engaging the attention of many soil scientists if green manuring should at all be advocated or not. Results of many experiments on green manuring conducted in recent years have caused a damping of enthusiasm for green manuring. Probably it will be unwise to compare green manuring with ammonium sulphate or urea in its efficacy to raise crop production. For obvious reasons the nitrogenous fertilizers applied in adequate quantities should be effective in raising the crop yields more than the green manure, in the current year of application. Further, the practice of growing a green manure crop *in situ* too has its own limitation. With demand for greater food production farmers do not like to sacrifice a food crop in order to raise a green manure crop. Apart from this limitation what is important is that an Agronomist should be careful in growing the green manuring crop and all soil factors limiting its optimum growth and nodulation of its roots must be eliminated. In the acidic soils of the plateau region of Chotanagpur in Bihar some studies were made to overcome the principal deficiencies of the soil so that a good green manuring crop could be grown satisfactorily. They are briefly described below :

(*a*) *Role of lime phosphate, molybdenum and seed inoculation on green manuring for wheat.*

A replicated field trial using sunhemp as the green manure and wheat as the test crop was conducted for 5 years to see the effect of lime phosphate, molybdenum and seed inoculation on green manuring for wheat.

Treatment	Yield of wheat mds/acre 1960-61	61-62	62-63	63-64	64-65
Control	3·6	4·5	6·9	3·4	6·7
G. M. + lime (once in 5 yrs.)-(L)	12·1	9·0	10·9	6·4	9·9
G. M. alone	3·4	5·2	7·5	6·4	9·2
G. M. + L + 40 lbs. P_2O_5/ac. (P)	19·0	15·3	16·0	11·3	12·4
G. M. + L + P + Mo at 2 lbs. Ammon. molybdate	17·7	13·8	14·2	9·7	11·8
G. M. + L + P + Mo + seed inoculation	18·3	13·9	14·9	10·4	13·0
C. F. at 5 %	3·04	2·13	4·2	2·3	2·52

(*b*) *Methodology of phosphate application for green manuring.*

An experiment in the alluvial zone of the State had shown in the past that the availability of phosphate and the yield of wheat succeeding the green manure increased if the superphosphate is added to the soil at the time of the burial of green manure rather than at sowing of wheat. Thus experiments were undertaken to find out if a similar effect of incorporating phosphate with the green manure resulted under Chotanagpur conditions. For this purpose Kalai was grown *in situ* as a green manure crop and wheat was taken as the test crop in a replicated trial at Kanke. The yield data of wheat are presented below :

	Yield of wheat grain mds/acre* After Kalai green manuring				
	1960-61	61-62	62-63	63-64	64-65
G. M.	22·7	14·0	17·0	8·09	17·4
G. M. + P_1	19·6	17·9	17·6	13·3	22·8
G. M. + P_2	25·9	16·9	13·0	9·7	17·2
G. M. + P_3	25·7	18·3	18·0	10·4	22·4
N only	27·5	14·4	17·7	9·9	16·4
N + P_3	34·0	26·3	22·4	15·1	22·3
C. D. at 5%	4·33	3·12	N.S.	N.S.	5·31

*The soil was limed uniformly before the green manuring crop was sown.
P_1—40 lbs. P_2O_5/acre as superphosphate applied during the incorporation of G. M.
P_2—20 lbs. P_2O_5/acre as superphosphate applied during the incorporation of G. M.
20 lbs. at sowing.
P_3—40 lbs. P_2O_5/acre as superphosphate applied during the incorporation of G. M.
N—40 lbs./acre as ammonium sulphate used at sowing of wheat

Both of these experiments very clearly indicated that the effectiveness of green manure depended on lime and phosphate application properly. This soil should be limed according to its lime requirement and phosphate should be applied to the green manuring crop at sowing. The choice of the green manuring crop is also important. Chandrani *et al* (1956) found that cluster bean and sunhemp were better green manuring crops than cowpea or soybean. Sannasi Raju (1952) obtained 1753 lbs. per acre of paddy from no manure treatment as against 36/26 lbs. per acre from the green manure treatment. Ghosh *et al* (1956) at the C. R. R. I. Cuttack found that green manuring is more efficient than ammonium sulphate on an equal nitrogen basis and the response of 20 lbs. of N as green manuring is similar to that of 30 lbs. of N and A/s. in the yield of paddy. Sivaraman (1961) reported that at C. R. R. I. Cuttack continued use of green manuring at 5000 lbs. per acre supplemented by fertilizers has been effective in not only maintaining a high level of production over a period of six years but it has stimulated a gradual increase in production as well. These are some of the promising results of green manuring experiments done in recent years. An exhaustive account of work done in previous decades has been given by Mukherjee and Agrawal.

II. Legumes

It is well konwn that legumes add nitrogen to the soil. Unfortunately this knowledge has not been properly utilised in most of our programmes for increasing the productivity of soils. Rotations are recommended without due trials over a reasonable period of time. Legumes are included in these rotations without any consideration for the nitrogen donating powers of the recommended legumes under the soil and climatic conditions of the region concerned. For example a rotation experiment conducted at Sabour during the years 1950-53 at Sabour in Bihar, very clearly pointed out that under the soil and climatic conditions of that region *Kalai* (*Urid* (*Phaseolus mungo*) is about the best legume. Wheat yield, if it follows a *Kalai* crop, is comparable to that grown with 40 lbs. of nitrogen as ammonium sulphate (Mandal & Mukherjee

1953). The yields of wheat after soybean and guar (Cymopsis psoraloides) were much less than those obtained after *Kalai* and *mung*. Between these two crops of *Phaseolus* group Kalai was distinctly better than *mung*. It was observed that the patterns of mineralisation of nitrogen were different in different legumes (Mandal *et al*, 1955).

III. Lime

Acid soils must be limed for successful crop production. Here again this common knowledge has been sadly neglected and basic trials to make this know-ledge effective have been lacking. In the eastern region of India comprising West Bengal, Assam, Orissa and Bihar the extent of acid soils would probably exceed 30 million acres. Yet liming of the acid soil still remains a text book knowledge. How lime can promise to be effective in bringing about an agricultural revolution in certain areas, is evident from the results of experiments conducted in the acidic soils of Chotanagpur Plateau of Bihar.

Liming was tried out in the uplands of Chotanagpur for the cultivation of groundnut during the second and third decades of this century with some success but the importance of liming was ignored on account of the predominance of paddy cultivation in the cropping pattern of the region. The Field Experimental service during its early years, known as Manurial Table Scheme, introduced trials with lime in cultivators' fields. The results were not very promising. The next attempt at the improvement of soil fertility by applying lime was made in an acid soil farm at Islampur in Purnea district during the years 1951-53. Lime was applied in accordance with lime requirement worked out by Dunn's method and paddy, maize and wheat were grown. Maize and wheat responded to lime but not paddy. The lime requirement of this soil was fixed at 2 tons per acre and the liming factor was worked out as 1·0. It was also estimated that the reduction in pH due to leaching during monsoons is to the tune of 0·2 pH units. Investigations on this soil further revealed that within a block of 4000 acres the pH varied from 4·7 to 6·8. These studies also indicated the need for further investigations preferably in the main acid belt of the State *viz.* the Plateau region of Chotanagpur and the hilly district of Santhal Parganas. The experience gained at Islampur suggested studies not only on lime requirement of acid soils, but on frequency of liming, differential response of crops to liming, quality and fineness of liming materials, method of application of lime etc. The ten-year period from 1956-66, may be reckoned as the peak period of these investigations in the acidic red loam soil of Chotanagpur. A series of field experiments followed by laboratory studies have brought about the following (Mandal etc. 1965, 1966):

(1) Crops differ in their response to liming. The highly responsive *kharif* crops are cotton, groundnut, *rahar* and soybean. Crops showing medium res-ponse are maize, *juar*, *mung* and *urid*. Crops that exhibit little or no response are paddy and small millets. Amongst rabi crops gram, pea and lentil are more responsive than wheat. Linseed too responded to liming but mustard did not respond. Barley responded in one year but not in other years.

(2) Lime should be applied to the soil to its full requirement dose in one lot. The beneficial effect continues for five years after which the soil should be limed again. During the quinnquenial period the cropping should be adjusted in accordance with lime responsiveness of the crop.

(3) The pH of the soil drops by 0·2 units after every monsoon and the exchangeable Ca by 1·5 m.e./100 grams of soil.

(4) The quality of limestone is not of much consequence if the lime is applied in appropriate quantities.

(5) There is no advantage in applying lime at depth. Surface application of lime followed by its thorough mixing in 0–4″ layer is fairy effective.

(6) It is not necessary to crush the limestone beyond 10 to 20 mesh size. However finer the mesh, quicker is the rise in pH.

(7) The lime requirement of an acid red loam soil of sandyloam texture and pH 5·6 or 5·7 is about 1 ton of lime per acre. For a particular pH, as the texture becomes heavier the lime requirement will increase by an additional quantity of 400 lbs. of lime per acre. Similarly for each crop or rise in pH by 0·1 unit the amount of lime can be calculated by adding or substracting 400 lbs. of lime per acre.

(8) Lime requirement determined by Dunn's serial potentiometric fixation method has been found comparable to that determined by actual field experimentation. The liming factor has been found to be 1·0.

IV. Steel Factory Slags

Steel slags are used in large quantities as fertilizers in Europe, particularly in Germany. They are rich in lime and phosphate, containing about 50% calcium oxide and 16% phosphate. In India about 6 lac tons of steel slag are produced every year. Unfortunately, this large quantity of slag is not used in our country as a fertilizer, primarily because of its low phosphate content (ranging from traces to about 7%, average being 3% in basic slags) and difficulties in rendering it to powdered form. The Indian slag is, however, quite rich in lime as it contains, on an average about 40% calcium oxide. Blast furnace slags are richer in Calcium but poorer in phosphates.

(a) *Role of basic slag in nitrogen accretion of the soil*

Basic slag influences soil nitrogen in several ways, *viz.* in fixation of atmospheric nitrogen, reduction of the loss of soil nitrogen and helping the nitrification process. The importance of basic slag in relation to the nitrogen problem and improvement of land fertility by organic matter and phosphate was amply emphasized by Dhar (1955). According to him the Tata basic slags and other phosphates when used with oraganic matter not only fix atmoshpheric nitrogen, supply available phosphate, increase crop production and improved the fertility of normal soils but also reclaim the usar and alkali soils permanently. Mitra and Shanker (1955) also showed that the application of basic slag resulted in the improvement of alkali soils poor in nitrogen and carbon, particularly in presence of organic matter. Dhar and Gaur (1957) demonstrated that in presence of finely divided basic slag the fixation of nitrogen was greater than in absence of it. In a series of papers Dhar in 1956 stressed that with all types of organic matter mixed with basic slag, land fertility could be enormously increased. All over the world, in composting F. Y. M. or its ploughing directly into the soil, addition of basic slag or other phosphates seems useful for permanent land improvement and agriculture. Tata basic slag has been found to improve nitrogen fixation in Indian soils mixed with cowdung, sucrose, etc. The phosphates of calcium increase nitrogen fixation more markedly than those of iron and aluminium (Dhar, 1956). Further he has indicated that phosphates stabilise proteins in soils. Phosphates are helpful in composting plant materials by fixing atmospheric nitrogen. Composting water hyacinth with basic slag results in an excellent manure for tropical soils and Dhar (1956) therefore, recommends that water hyacinth should be mixed with basic slag and utilized in humus increase and conservation of soils. According to him organic manuring

is not suitable in soils rich in Fe, Al and Triphosphates. These compounds have to be partially converted into Ca and Mg phosphates by the action of limestone or dolomite or free lime or basic slag before organic manuring can be profitable. Organic manure plus calcium phosphate or basic slag is conducive to maintenance of soil neutrality and increase of humus.

Various types of organic matter like wheat straw, paddy straw, grasses, legumes, water hyacinth, F. Y. M., peat, lignite, bituminous coal have been used and marked N–fixation takes place with these substances, more in light than in the dark. When Ca–phosphates, including basic slags, are added to the organic matter, the nitrogen fixation and fertility considerably imporve. In presence of light 25–40 mg. of N are fixed per gram of carbon of the organic matter oxidised. In the dark the fixation is half of that in light but in presence of phosphates added at the rate of 100 lb P_2O_5 per acre of land, the nitrogen fixation is doubled both in light and in the dark. Composting of plant residues and city refuge basic slag and rock phosphates have been found to increase nitrogen fixation.

Mitra and Shanker (1955) showed that when rock phosphate or basic slag are added with organic matter like sunhemp or alfalfa, they retard nitrogen loss from the alkali soil in which nitrogenous fertilizers were added either in the form of ammonium sulphate or Na NO_3 to a greater extent. The efficiency of basic slag is greater in retarding the loss of nitrogen in comparison to rock phosphate. Mitra and Singh (1957) found Tata basic slag more efficient than Bihar rock phosphate in oxidation of sunhemp in alkali soil. With basic slag, N fixation was only observed in those cases where initial nitrogen of the system was high. Phosphatic amendments check the nitrogen loss from alkali soils when sunhemp is applied to it. Dhar and Chojer (1956) discussing on the retarding effect of lignite and different phosphates on N loss in soils observed that calcium and magnesium phosphates including basic slag furnish soluble Ca and Mg ions in the system to form nitrites which are more stable than ammonium nitrite with the consequence that there is decrease in the loss of nitrogen. According to Dhar and Singh (1964), loss of N which is found in the composting of highly proteinous organic materials, can be checked by incorporation of paddy straw and phosphates in the soil. Mineral phosphates including basic slags create nitrites of Na, K and Ca which are stabler than NH_4NO_2 and nitrogen loss decreases.

(*b*) Role of basic slag in supplying phosphate and neutralising soil acidity.

A series of field experiments conducted for the past few years at the Agricultural Research Institute, Kanke, (Ranchi) revealed that crop production in acidic uplands of Chotanagpur comprising about 40% of the agricultural land of that region, can be greatly increased by using lime in conjunction with nitrogenous and phosphatic fertilizers.

Since the steel slags are rich in lime and also they contain some *phosphate*, it was thought desirable to try out their efficacy as both liming and phosphatic materials. A number of field experiments were thus laid out. They are briefly described as follows :

(*A*) *Utilisation of basic slag as a phosphatic material.*

Crops : Peas, wheat, gram.

Series : (*i*) Limed (*ii*) Unlimed.

(Lime applied at amount 1 ton per acre.)

(*i*) Duration of the experiment 4 years (1961–65).

(*ii*) Basal manure given in appropriate doses of N and K.

(*iii*) Phosphate applied at 60 lbs. of phosphate in the form of different phosphatic materials, including basic slag.

TABLE I

Average yield of peas in md/acre

Phosphatic materials used	Under unlimed condition	Under limed condition
None	1·1	6·0
Superphosphate	3·2	13·5
Rock phosphate (in posted)	2·1	9·9
Bonemeal	2·9	9·8
Basic slag	8·3	11·7

Conclusions: (1) Under unlimed condition basic slag is superior to other phosphatic fertilizers.

(2) Under limed conditions superphosphate is the best phosphatic fertilizers, closely followed by basic slag.

(3) Basic slag is effective not just as a phosphatic fertilizer, but also as a liming material, as evident from an extra yield of about 5 mds. per acre of pea obtained in this treatment over the yield obtained from the superphosphate treatment.

(*b*) *Wheat and Gram*

(*i*) Duration of experiments 2 years (1964–66)

(*ii*) Phosphate applied @ 40 lbs. of phosphate to wheat and @ 60 lbs. to gram.

TABLE II

Average yield

Phosphatic materials	Wheat		Gram	
	unlimed	limed	unlimed	limed
None	8·9	15·8	11·2	27·2
Superphosphate	11·2	16·9	14·7	30·9
Rockphosphate	11·3	16·2	11·6	30·0
Basic slag	13·2	17·5	20·7	30·1

Conclusion: Same as in the case of peas.

(*B*) *Slags as liming materials.*

Slags from different steel factories were also compared to find out if they are as good liming materials as the market lime or limestone powder and also if

some slags are better than others. Under this project too a few crops have been grown viz., wheat, gram, maize and groundnut. Slags were applied @ 1 ton of calcium carbonate equivalent and a basal dose of nitrogen @ 40 lbs/acre to wheat and maize and @ 10 lbs to gram and groundnut was given. The yields in 1965-66 are as follows :

TABLE III

Yield in md/acre

Slags	Wheat	Gram	Maize	Groundnut
None	12·6	7·7	23·4	24·0
Lime (Limestone)	15·9	17·1	29·2	28·5
Bhillai blast furnace slag	18·0	21·0	28·5	27·7
Bhillai open hearth slag	14·5	15·0	24·1	31·6
Rourkela open hearth slag	16·7	19·4	25·7	27·9
Rourkela L. D. slag	16·9	16·7	27·7	30·0

Indications : There are strong indications that on equal calcium carbonate basis the slags are as good liming materials as the ordinarly limestone normally used for liming. Some of them *e.g.* the Bhillai slag is a little better than other slags.

India is producing at present about 6 lac tons of steel slags, annually, of which TISCO produces over 1 lac ton. When Bokaro Steel Factory starts production, this amount may go up to 3 to 4 lac tons in Bihar alone. This can be used to supply adequate quantities of lime and appreciable quantities of phosphates to about 3 to 4 lac acres out of estimated 30 lac acres of acid soils requiring lime in Bihar. At the same time this will alleviate the slag disposal problem of the steel industry. Steel slag is however a very hard material and cannot be used unless it is powdered well. The National Metallurgical Laboratory has been induced to devise an easy method by which powdered slags may be manufactured.

V. Microbial inoculation

The possibility of increasing crop production through soil or plant inoculation with appropriate microorganisms (also called "bacterization") was realized in Europe and U. S. A. towards the end of the nineteenth century or so. Of the several microorganisms used for this purpose, the root-nodule bacteria or *Rhizobium* are the most common, their inoculum being manufactured and used for improving leguminous crops in mass scale in countries of North America, Europe, Japan etc. On the other hand the use of some other microorganisms is limited to certain areas only and critical evidence to support their usefulness still remains to be furnished. In recent years some newer kinds of organisms like phosphate dissolving organisms, blue green algae have appeared promising. A brief account of the investigations on microbial inoculation of different kinds in crop production in India with special reference to work done in the State of Bihar is presented here.

(a) Root-nodule bacteria (Rhizobium)

In many parts of the world like U. S. A. where fertilizer consumption is also very high, the farmer practices legume inoculation as a matter of routine each time he sows the crop small cost involved in this practice is considered as an insurance against crop failure due to the lack of effective strains of *Rhizobium* in the soil.

Suitable laws have also been enacted to standardise and maintain quality control of the cultures supplied by firms. In India although legume inoculation has been on the list of recommendations particularly for crops like berseem (Trifolium alexandrinum) for almost as long a period as in U. K. little work has been done to evaluate, improve and popularise this practice and its mass scale adoption remains to be attained. Since legumes draw 80% of their nitrogen requirement through symbiosis with *Rhizobium* legume inoculation can be expected to play a major role in nitrogen economy of the soils and production of the leguminous food and fodder crops. Some recent reports can be mentioned in this connection. A significant increase in the yield and nitrogen uptake of berseem from seed inoculation with the culture of the root-nodule batceria was reported by Malik and Batra (1959) although they noted that a small dose of a nitrogenous fertilizer may give a good start to the crop in the early stages of the growth. Seed inoculation at 4 oz culture mixed with milk per 20 lbs. of the seed may increase the yield of soybean by 10 to 40% according to Raheja (1959). Some varieties of French beans not known to grow in Delhi plains could be grown successfully by Sen and Sen (1966) with the help of organic manure as well as inoculation with suitable strains or *Rhizobium*. The latter almost doubled the yield.

In Bihar exploratory field trials have been conducted from time to time with a view to improving the stand of the existing leguminous crops. Many of these trials have shown increase in the yield of gram (Cicer arietinum), *urid*, *mung*, Khesari etc. The increases in the yields in most cases were however not of high order. It is therefore likely that some conditions in the soil were operating adversely to the realisation of full advantages from the legume inoculants. It is also possible that these bacterial preparations required further improvement. Nevertheless these results hold out great promise for the tapping of the cheap means of legume inoculants in Bihar for increasing the out put of these crops, occupying a very important position in the diet of both man and his cattle from their present low yield.

VI. Azotobacter

Besides nitrogen fixation this organism is also credited with the production of growth promoting substances and ability to keep in check the pathogens in the rhizosphere of the plants. It is one of the so called bacterial fertilizers currently in use in U. S. S. R. and some East European countries. Although certain reports of the beneficial effects of azotobacter inoculation have also come from other countries this method is generally considered not quite effective.

In India Azotobacter inoculation of seeds and seedlings has been claimed to increase crop yield by many workers in the past such as Vyas (1934) on maize, Bahadur and Sahasrabudhe (1936) on rice, and Karunakar and Rajgopalan (1936) on sorghum. The latter workers recorded an increase of 28 to 34% in the yield of grain and 36 to 74% that of straw in green house tests as well as 22·7% increase in the grain weight in fields. Their results deserve special consideration as they were subjected to strict statistical analysis and were found to be highly significant. Recently Sundara Rao *et al* (1963) also noted increase in the yield of wheat and ragi in pot cultures resulting from seed inoculation with azotobacter. Under field conditions however over a period of 3 years the effect of this inoculation on wheat was non-significant while on peas it was significant for one year but non-significant for 2 years. Soaking of rice seedlings with azotobacter culture in pot cultures has been reported to be beneficial from Cuttack (1965).

Thus while a critical evidence in favour of the azotobacter inoculation is lacking at present the possibility of its beneficial effect cannot be ruled out.

Certain suggestions can be made for future investigations. Since work both in Bengal (De 1952-54) and Bihar (Mukherjee *et al* 1955) has shown that azotobacter are absent in many soils, their inoculation along with soil treatments to make growth conditions favourable to these organism may be fruitful. Such soil treatments could be use of energy yielding organic matter, phosphate, lime and certain micronutrients like molybdenum.

(*C*) *Microorganisms associated with phosphate availability.*

Many microorganisms are known to increase the availability of soil and fertilizer phosphorus and their utilization for this purpose may be feasible. These organisms may be broadly divided into 2 groups, (*i*) Those which release phosphorus from organic compounds through the mineralization of the organic matter, and (*ii*) which solubilise insoluble inorganic phosphates through various mechanisms such as inorganic and organic acids, chelating effect of the organic compounds and hydrogen sulphide produced by them. To the first group belong such organisms *e.g.*, *Bacillus megaterium* var, phosphaticum whose inoculum known as phosphobaterin is commonly used in U. S. S. R. Investigations including P_{32} studies with the culture of this and some other organisms at I. A. R. I. have confirmed phosphorus release by them. In pot experiments, including some at Ranchi in Bihar, phoshobacterin cultures increased the dry matter yield of crops like soybean though under field conditions the results could not be reproduced.

Several microorganisms belonging to bacteria, fungi and actinomycetes capable of solubilizing insoluble phosphates like rock phosphate, basic slag etc. have been isolated from soils of Delhi, Bihar (Ahmed 1965) and Bengal. Some of these organisms have high phosphate dissolving ability and have therefore the potentiality of being used for the utilization of the insoluble phosphates of low grade which occur in substantial amounts in certain parts of the country, particularly in Bihar.

(*D*) *Blue green algae.*

Algae commonly grow on rock surface, in cultivated or virgin lands, tanks, canals, rivers, near wells and even on the roof and walls of the buildings. In fact they are abundant in the habitats where moisture is adequate, light accessible and growing medium is not too acidic but preferably neutral to alkaline. While these organisms may cause pollution of water and damage to buildings etc. They can also be used for human welfare. It may be possible to use some of them as food for man, fodder for cattle and as feed for fish as well as for purification of sewage, reclamation of 'usar' lands and for increasing crop production. Increase in rice production with the help of some blue-green algae, for which some pioneering work has been done in Bihar, is discussed here. Recent work by Dhar and Coworkers, (1965) at Allahabad and Lalwani *et al* (1965) Subrahmanyan and Sahay (1964), Shankaran (1966) at Cuttack Rice Research Institute are more or less in agreement with Bihar results.

Many blue-green algae are able to absorb nitrogen from the air part of which may be exc:eted into the soil and the rest remains fixed up in their cells and released later after they die and their bodies decompose. Nitrogen enrichment from *Tolypothrix tenuis*, a blue-green alga was 18 to 41 lbs. per acre in some Bihar soils. Even higher enrichment in nitrogen has been reported for some West Bengal and other soils. Algae may also add considerable amounts of organic matter. In some Bihar soils it was estimated at 4000 lbs. dry matter per acre equivalent to 175 mds. green manure with *dhaincha*. Some recent investigations are suggestive of the role of algae in the availability of soil phosphorus. By utilizing carbon

dioxide and releasing oxygen, algae may also promote the aeration of the roots of rice plants under water-logged conditions. Some recent studies at I. A. R. I. New Delhi are also suggestive of the production of growth promoting substances by algae.

These facts suggest the possibility of increasing rice production through inoculation with beneficial algae. Investigations to explore this possibility were started for the first time in India in 1956 by the Department of Agriculture Bihar. In the following year it was found at Sabour that the inoculation of the field with *Tolypothrix tenuis*, 20 days before transplantation increased the yield of rice considerably and this effect was equivalent to that of 175 mds. per acre of green manure with *dhaincha.* Pot experiments, and field experiments conducted thereafter in Sabour (Bhagalpur) Farm and in cultivators' fields in Bikramganj area of Shahabad District have fully confirmed the beneficial effect of the inoculation of the fields with *Tolypothrix tenuis* on rice yield and the effect was comparable to that of 40 lbs. N/acre (*i.e.* $2\frac{1}{2}$ mds. ammonium sulphate or $1\frac{1}{4}$ mds. urea). The results of Farm experiments during 1962-66 show that paddy yields are raised from 25·0 mds per acre to 36·0 mds/acre on an average due to algal inoculation. In cultivators' fields the yields have been raised from 26·0 to 36·0 mds/acre due to algal inoculation during 1964-66.

Rice production can thus be increased by the use of some blue-green algae like *Tolypothrix tenuis* and a substantial cost on nitrogenuous fertilizers saved. To make available this cheap means of algal inoculation it would be necessary to grow the required alga on a mass scale and devise a form of its preparation convenient for use by the cultivators. Further Research work must be conducted in that direction.

In conclusion it may be reiterated that soil fertility can be maintained at a reasonably high level by judicious use of organic manures, inclusion of right type of legumes in rotation, application of lime if the soil is acidic, use of steel factory slags, to meet calcium, phosphate and to a great extent nitrogen requirements of the soil, and the inoculation of useful soil microorganisions *e. g.*, root nodule bacteria, azotobacter, phosphorus dissolving bacteria and blue green algae.

Summary

It is now very well recognised that with fertilizers and irrigation water our crop production can be raised not only to the level of self sufficiency, but to a state of surplus as well. Unfortunately for us the production of fertilisers is likely to lag behind the demand for fertilisers that is gaining momentum. Under these circumstances, it is necessary to recognise the utility of other means of increasing the productivity of our soils. The role of organic manures in this regard is well known. The same may be said of the efficiency of legumes. Curiously enough, the Agronomists of our country have developed a tendency to consider green manuring and legumes cultivation as practices of secondary importance. In many cases failure of green manuring and legumes in rotation in enriching soil nitrogen have contributed to diffident outlooks in these regards. The limitations inherent in the soil for the success of green manuring and selection of right types of legumes, on the basis of their nitrogen donating capacities, should be studied carefully. Work done at the Agricultural Research Institutes at Sabour, (Bhagalpur) and Kanke (Ranchi) in Bihar confirm the need for such studies. Acid soils remain unproductive if they are not limed properly. Green manuring and legume cultivation will be much more effective if acid soils are limed before the cultivation of

legumes or green manuring crop. Inoculation of rootnodule bacteria and application of phosphates and, if necessary, molybdenum, should also be resorted to for successful green manuring or legume cultivation. Inoculation of blue green algae would raise the yield of paddy substantially. Work done in the said Institutes in Bihar in recent years has proved, beyond doubt, the high efficacy of these measures. Basic slags have been found to be efficient lime and phosphate carriers in Bihar, and studies at Allahabad show, that they are helpful in the accretion of nitrogen in the soil when they are applied in conjunction with organic wastes.

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Some Practical Experiences in the Maintenance of Fertility of a Red and Lateritic Soil under High Yielding Crops

By

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The writer of this article is grateful to Dr. N. R. Dhar for inviting his views and experience on some aspect of the problem of land fertility and its improvement to be presented at the proposed International Symposium. The problem has assumed greater importance in the light of pressing need for increasing production to meet food shortage. Opinion has been expressed that at the present rate of growth in world population the shortage of food to meet required consumption will progressively increase leading to starvation death of an estimated 800 million people by the end of the present century.

The writer, however, is a staunch believer in the inventive capacity of the human brain which has found means to meet pressing need in the past and will not fail to do so here also. Moreover, the general consciousness is steadily rising for better living and for family planning so that by the end of this century, or soon thereafter, the world population will be more or less stabilised. Accordingly in the writer's opinion the anticipated death of 800 million through hunger, an anticipation based on the present rate of growth of population and food production, will not happen. But that there is urgent need for increasing food production cannot be overemphasised. The present symposium, therefore is very welcome.

But the writer's diffidence in contributing anything which will prove useful at the symposium will be evident from the fact that he has been more or less out of touch with science and soil fertility studies for about a decade and a half. After retirement from the U. P. S. C. in 1964, he has been able to devote some time in farming in a very humble way. He can, therefore, broadly record here his practical experiences relating to very small part of the prohlem *viz.*, increase in crop production and maintenance of the fertility of the land in a red and lateritic belt.

He, however, desires to begin by saying that a break through in greater food production has already been made by research workers who have evolved a few very high yielding strains of paddy and wheat. These strains are dwarf and erect to allow maximum penetration of sunlight for greater carbohydrate synthesis and which, particularly the paddy, are not season bound and are capable of absorbing and assimilating substantial amounts of nutrients thereby giving very high yields. In the writer's opinion this is just the beginning of many more still higher yielding strains to follow during the next few years.

The extension of these high yielding strains to cover wide areas in shortest possible time to wipe out food deficits poses the problem, so far as the country is concerned, for the farmers, the Government, the agricultural extention staff and the agricultural scientists. The farmers must agree to take to these improved

strains. They are hesitant on account of the extra expense and labour involved, but the writer's close contact with them indicates that they will readily agree to grow these strains if the prices of the produce are profitable. Leaders, politicians, members of Planning Commission all say in a loud voice that agriculture is the biggest industry of this country, yet the profit on agricultural produce is much lower than that on produce in a pharmaceutical, chemical, engineering in fact in any other industry. The Government with their levy, or Food Corporation with their procurement, offering low unattractive prices are creating diffiulties. The financial strength of our farmers, most of whom are small farmers, does not permit large investment by them required for the purpose, manures and fertilizers which are so essential here are hopelessly in short supply and the extention staff not only lacks in the know how but also in organising and administrative ability. But a happy sign is that a concerted action by all are going on to improve matters on all fronts and this is just yielding good results. Therefore, unless the progress is retarded by the lack of foresight in fixing unremunerative levy or procurement prices, India should be self-sufficient in food in the next ten years or even earlier.

On the agricultural scientists it devolves, however, to see that this country's already impoverished soil is not ruined by the effort to grow such high yielding strains year after year. With these strains the manurial pattern is fast changing to what is done in hydroponics or sand culture *i.e.*, to grow the crop on added nutrients to the extent it is capable of assimilating more or less disregarding what the soil contains in respect of those nutrients. Generally the major nutrients NPK only are applied to the soil and in order that continued use of heavy doses of such chemical fertilizers does not leave any harmful effect on the soil a fairly heavy dose of 4 tons of compost per acre has been recommended. The nitrogenous fertilizer should be used in the form other than ammonium sulphate *i.e.* as urea, ammonium phosphate etc. so as to prevent the possible development of acidity in the soil. The writer may, however, report that he has applied ammonium sulphate with 1½ to 4 tons of compost to his paddy land year after year without noticing any bad effect on the soil although Japanese work indicates a slight degradation of the soil under paddy with repeated applications of ammonium sulphate. Whether the difference is attributable to the method of water logging of paddy fields and higher temperature in this country as against ever flowing irrigation of paddy lands and lower temperature in Japan, is difficult to say without controlled experimentation but from a priori consideration it may appear to be so. For the high yielding strains of wheat, however, the use of ammonium sulphate should be avoided as far as is possible and where it is not possible because of shortage of fertilizers a small dose of lime should be applied along with ploughing immediately after harvest of the crop. This small dose of lime, the quantity to be varied according to local conditions, has been found by the writer to help the soil maintain its tilth.

As a result of the heavy growth of the improved strains due to high doses of NPK deficiencies of minor elements and of some of the major elements like magnesium and calcium may arise sooner or later in the soil and it becomes necessary to counteract these deficiencies from beforehand to maintain the fertility of the soil especially of red and lateritic soil which is highly leached. As mentioned earlier the writer's farm is situated on such a soil. In his orchard leaves of mangoes, lichis, jackfruits, custard apples and other fruit trees showed signs of deficiency which was corrected by the application of dolomite. The leaves of cashewnut, coconut etc. indicated deficiencies corrected by dolomite and lime. The absence of fruiting in citrus plants was corrected by spraying of zinc and

copper sulphates and the lack of cob formation in hybrid maize was corrected by a trace of boron in the form of boric acid given with the fertilizers. In his water culture experiments with paddy plants some 37 years ago at the Dacca University the writer had noticed that absence of magnesium killed the plants and that the luxurious vegetative growth due to excessive dose of nitrogen leading to no grain formation was corrected by the application of boron (4 p.p.m). In the light of these observations he has applied 1 to 3 Kg. of dolomite per fruit tree. For the paddy land, as a prophylactic measure, he is applying 1 Kg. boric acid per acre every second year, has applied 40 Kg. of dolomite per acre once for all and 10 to 15 Kg. per acre of powdered lime (as available in the local market) along with ploughing soon after harvest every year. The soil so far has remained in good shape.

It may be stated that the writer's red and lateritic soil farm is situated on a highly porous sandy upland. It is difficult to maintain any head of water for long even during the monsoon for the paddy crop Soon after the rains the land dries up quickly. Until his retirement in 1964 *i.e.*, when he was away, the land was under paddy cultivation with 1½ ton of cowdung compost and a basal dose of 20 lbs (9 Kg) each of N and P_2O_5 per acre and was yielding on an average of 650 Kg per acre of semi-coarse paddy. After he was able to pay more attention the same land yielded during the last Kharif season 1350 Kg. of very fine scented paddy with 2 irrigations from a nearby pond and little over 1600 Kg. of coarse paddy (Taichung 65) per acre without irrigation. The applications of manures and fertilizers were as follows :

		Very fine scented paddy	Coarse Paddy (Taichung 65)
A.	As a basal dose before transplantation	Per Acre	Per Acre
	Cowdung compost ...	4 tons	4 tons
	N as am. sulphate ...	10 Kg	15 Kg.
	P_2O_5 as superphosphate ..	10 Kg	25 Kg.
	K_2O as potashchloride ...	9 Kg	18 Kg.
B.	As top dressing just before ear emergence N as am. sulphate ...	3½ Kg	7 Kg.
C.	No. of irrigations from a nearby pond ...	2	Nil
D.	Yield as dressed grain...	1350 Kg.	1600 Kg.

It may be seen that the yield of Taichung 65 was about ⅔rd of what is generally obtained with this strain elsewhere in India. This was due to lower doses of $N + P_2O_5$ and wider spacing at transplantation than are usually adopted for this crop and of course to the sandy nature of the land. But attention is here drawn to the fact that Taichung can be grown fairly successfully on a sandy upland with the help of only monsoon rains and to the various precautions required to be taken to maintain the fertility of the land in a red and lateritic belt when the land has been placed under such high yielding crop year after year.

Summary

In the writer's opinion the anticipated starvation death of 800 million people by the end of this century will not happen. It is submitted that on the one hand the inventive capacity of the human brain will meet the situation through adequate food production and on the other the rise of general consciousness for better living and for family planning is likely to stabilise the world population in the next 40-50 years.

The breakthrough in greater food production has already been made by the evolution of very high yielding strains of paddy and wheat and it devolves on the agricultural scientists to see that the already impoverished soils of this country are not ruined by the application of very heavy doses of chemical fertilizers required to grow these strains. A brief account of the experiences of the writer has been given in regard to the precautions required to be taken to maintain the fertility of the land in a red and lateritic belt when the land is placed under such high yielding crop year after year.

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Land Fertility and its Improvement with Particular reference to North Bihar

By

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There is an urgent need for bringing about rapid increase in agricultural production in order to keep pace with the demands of the population which is growing at a tremendous rate. This situation demands that India should move from traditional agriculture to scientific agriculture. Scientific agriculture aims at improving the soil productivity of the land on a sustained basis as well as rational utilization and management of the land and water resources.

Soil productivity depends to a very large extent on the improvement of land fertility which is deteriorating day by day due to great pressure on land. Therefore such situation demands that land should be used according to capability. Besides, suitable cropping pattern, balanced fertilization, efficient management of the land should be taken up along with the control of various hazards including soil erosion, salinity, alkalinity and soil acidity.

In the context to the improvement of land fertility so far as North Bihar is concerned, it is of importance to have a knowledge of the soil of this area which is basic to all agricultural development. North Bihar soils are young alluvial soils and two broad soil divisions have been marked namely calcareous and non-calcareous. These soils are characterized by light texture frability, good aeration, free drainage and easy tillage condition. The major soil type is sandy loam and loamy sand whereas sub-soil have light to medium texture. Different soil types generally found in North Bihar have been presented in the following table :—

Soil type found in North Bihar expressed in % basis

Loamy sand	...	25 to 35
Sandy loam	...	60 to 80
Loam	...	9 to 14
Sandy clay loam	...	5 to 12
Sandy clay	...	10 to 20
Clay loam	...	5 to 15

The non-calcareous soils of North Bihar are neutral with a scatter of acid patches here and there. The calcareous soils are highly alkaline and usually contain 30-35% $CaCO_3$. There is a large area of saline soils within this division with extremely alkaline soils having bad physical conditions.

As regards the soil fertility status of the soils, the results of soil testing have yielded valuable information on this aspect. A soil test summary of Tirhut soils is presented in Table I.

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TABLE I

Soil Test Summary of Tirhut Soils

District	% of soil samples with												
				Organic Carbon			Available P			Conductivity in millimhos (Total soluble salt)			
	AC	pH NU	ALK	Low	Medium	High	Low	Medium	High	Normal	Critical for germination	Critical for growth	Injurious to most crops
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Saran	(1820) ×	37·2	62·7	(1820) 43·72	35·55	22·73	(1820) 67·82	25·43	6·75	(1335) 62·93	14·94	4·21	17·92
Champaran	(2333) 0·1	49·2	50·7	(2333) 30·74	35·1	34·16	(2333) 57·2	27·5	15·3	(1745) 82·9	10·2	1·9	5·0
Darbhanga	(1991) 0·02	40·08	59·9	(1991) 49·40	25·8	25·5	(1991) 63·9	25·74	10·36	(1323) 79·9	12·9	4·2	3·0
Muzaffarpur	(1272) 0·3	38·2	61·5	(1272) 52·1	28·1	19·8	(1272) 57·04	27·06	15·9	(913) 68·7	13·14	4·0	14·2

(Figure in parentheses denote the number of samples tested).

From the data it will appear that about 60% of the soil tested in Saran and Darbhanga and 57% of the samples in Muzaffarpur and Champaran are low in available phosphate. The nitrogen status of these districts have been evaluated by organic carbon percentage method which shows that about 50% of the soils tested in Darbhanga and Muzaffarpur are low, but in Champaran and Saran about 30% and 43% of the soils tested are low.

The analysis of total soluble salts content of the soils show that compared to other districts, large number of samples of Saran district lie in the range of such concentration which is injurious to plant growth. Besides saline soils, alkali soils are also scattered in different parts of Saran district.

From the foregoing report and the Soil Test Summary of Tirhut soils as given in Table I, it is further evident that low phosphorus availability, high fixation of phosphorus owing to highly calcareous soil conditions, low level of organic matter content and the problem of saline alkali soils are the important aspects which needs consideration in the improvement of land fertility as far as Tirhut Soils are concerned.

Therefore keeping in view the problems enumerated above, incorporation of green manure crops alone or along with phosphatic fertilizers prove quite beneficial in the efficient utilization of fertilizer phosphorus and in making it more available to corps. Besides, in increasing the humus content of the soil, it has an added advantage in reducing the salinity and alkalinity conditions of the soil. Experiments conducted at Pusa with Sanai (*Crotalaria juncea*) and Dhaincha (*Sesbania aculeata*) with 50 lbs of P_2O_5 to be applied at sowing or burying of green manure crops or half at sowing and half at burying of green manure crops showed that 25 lbs of P_2O_5 at sowing and 25 lbs of P_2O_5 at burying is superior to 50 lbs of P_2O_5 applied either at sowing and burying.

For the reclamation of saline and alkali soils with organic matter an experiment was conducted at Sepaya in Saran district. The results are presented in Table II.

TABLE II

Reclamation of alkali soils by organic matter

Treatment	Year and crop (1963-64) Paddy yield in mds/acre	Laboratory studies before sowing			
		pH	T. S. S. ppm.	Ex. Na m. e.%	Ex Ca m. e.%
Control	15·92	8·7	2100	1·80	3·34
Dhainoha @ 100 mds/acre	19·76	–	–	–	–
Dhaincha @ 200 mds/acre	20·17	–	–	–	–
		After harvest			
Dhaincha @ 300 mds/acre	24·83	8·68	2000	1·05	4·17

Significant at 5%

C. D.—2·30

From the results in Table II it is evident that application of Dhaincha @ 300 mds/acre is effective to some extent in reclaming saline alkali soils. The results of soil analysis indicate that after application of Dhaincha, exchangeable sodium content of soil has decreased, but pH, and total soluble salt content have not been materially affected.

Besides Dhaincha, other green matters such as *Argemone mexicana*, mixed lea powder and Gypsum were tried in Sepaya in 1964, 1965-66 in Kharif and Rabi for reclamation of saline alkali soils. Though the results were non-significant the mixed leaf powder @ 300 mds/acre gave higher yield compared to other green matters and gypsum.

For the reclamation of Usar soils in North Bihar the use of sulphitation press-mud is popular. Molasses and carbonation factory products are also used for this purpose, though sulphitation press-mud is more beneficial. Press-mud obtained from factories using sulphitation process not only contains a higher quantity of the essential plant nutrients but are also more balanced in their proportions and can be used in all types of soils. It has been found from the researches carried out at Sugarcane Research Institute, Pusa that sugarcane yields by the application of sulphitation press-mud compares favourably with fertilization at the rate of 40 lb N + 50 lb P_2O_5 per acre as oil cake and single superphosphate. When applied to different green manure crops, sulphitation press-mud greatly raises the green matter output, and compost made from sulphitation press-mud and cane-trash is richer in plant nutrients than compost made from cane-trash and cow-dung (Table III) and these sugar industry waste materials are of great value in building up the fertility of the soil, and in ameliorating the soils.

TABLE III

Analysis of composts prepared from different waste materials

	N%	P_2O_5%	K_2O%
Cane trash + cowdung	0·52	0·31	0·56
,, + carb. press-mud	0·35	0·42	0·78
,, + ,, + cowdung	0·50	0·34	0·68
,, + Sulph. press-mud	0·75	0·60	0·92
,, + ,, + cowdung	0·64	0·58	0·81

An application of 150 to 200 mds. of press-mud per acre is recommended with a view to provide the nutrient elements to the crop besides building up fertility of the soil. In case of fresh press-mud, this has to be incorporated in the soil before the monsoons to enable its decomposition. Where well rotten press-mud is available, it is incorporated as basal dressing at the time of land preparation prior to sowing or planting. Application of sulphitation press-mud showed beneficial effect to extent of 11·6 per acre increase in the yield of sugarcane, 6·8% in maize and 7·0% in wheat in the second cycle of rotation period.

The organic wastes and different species of weeds, which grow in this vast tract of North Bihar can be utilised for green manuring and composting material. Addition of phosphate at 10–20 lbs per compost heap in course of preparation enhances the nitrogen content of compost and makes more phosphate available.

Recently trace element fertilization has received attention for soil management in North Bihar. Continuous cropping and increasing use of macro elements are exhausting gradually the minor elements needed for successful growth of crops. Highly alkaline soil reaction is also restricting the mobility of micro-elements. A number of experiments with micro-elements have been carried out on cereals, legumes and vegetables in sandy loam soils of North Bihar. Encouraging results have been obtained with different micro-elements on different crops.

Availability of both phosphate and micro-elements may be induced if phosphate fertilizers are applied in conjunction with (*i*) easily decomposable organic matters, (*ii*) green manuring and (*iii*) in depth placement with acid forming substances such as ammonium sulphate and sulphur.

Besides the measures discussed for the improvement of land fertility, so far as North Bihar is concerned, it is of paramount importance to use land according to its capability. Proper cropping pattern, efficient management of the land including its water resources and balanced fertilization are of utmost importance for the maintenance of soil fertility.

Conclusions :

Usar soils pose a serious problem in North Bihar. Steps should be taken to make best use of experimental results for reclamation of such soils. Due to heavy pressure on land and pressing need of the overpopulated areas for supply of food it may not be advisable to spare land for raising green manuring crops independently. In the circumstance, all the resources should be tapped to utilze sugar industry waste material which is quite in abundance because of a large number of sugar factories. Besides use of gypsum and application of compost prepared from the cane trash in conjunction with press-mud and cow-dung should be encouraged on a large scale. To add to it a suitable cropping pattern including legumes and cover crops should be drawn out for each tract.

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Possibilities of using microorganisms as seed inoculants for increasing crop production

By
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The problem of providing food to the nation is intimately connected with providing adequate proteins as its shortage in under-developed countries is acute. It is necessary, therefore, to meet this through the production of pulses of high protein content and through feeding the cattle with leguminous fodder of high protein value. In this connection there is an immediate need to examine the present position regarding the type of *Rhizobium* strains that are now prevelent in different areas under leguminous food and fodder crops. Investigations carried out so far revealed that the yields of these crops have been considerably low because of the poor quality of *Rhizobium* strains in these areas and inadequate supply of water and nutrients. Effective strains of *Rhizobium* have been isolated and after due testing are now being maintained at the IARI and a few other laboratories in the country for over 20 leguminous food and fodder crops. There is an urgent need to produce these cultures on a mass scale in order to distribute them to the cultivators growing food and fodder crops. It has been observed that the specificity of the *Rhizobium* strains in cases like pea, soybean and groundnut is closely linked up not only with the species but also with the variety of the crop in the particular species. Therefore careful investigation is essential to select the *Rhizobium* strains suited to the high yielding varieties of legumes that are being introduced in this country.

Even in U. S. A. where 4 million tons of nitrogen in the form of artificial fertilisers are produced, approximately 42% of the legume seeds planted each year are inoculated. It is therefore essential and prudent to make the maximum use of nitrogen available in the atmosphere which can be harnessed for increased production of legumes through seed inoculation in this country followed by suitable soil amendments especially that of addition of phosphates, boron, molybdenum wherever necessary and correcting for acidity through lime. This will facilitate the diverting of nitrogen fertilisers which are scarce, to the cereal crops.

The use of *Azotobacter* and phosphorus solubilising organisms has been found to result in increasing yields of cereal crops in specific cases. Carefully conducted experiments using radioactive isotopes P^{32} showed that seed inoculation with phosphorus solubilising organisms results in increased uptake of phosphate from tricalcium phosphate. The potentiality of these organisms needs to be exploited, for increasing the solubility of phosphates available in indigenous basic slag and rock-phosphate. Evidence is accumulating that the use of bacterial inoculants is more effective in soils of high fertility or when manures and fertilisers have been applied showing thereby that the contribution of these inoculants may be through synthesis of growth promoting substances. The use of microorganisms as seed inoculants is recommended for increasing crop production in order to increase the beneficial effects of added manures and fertilisers and thereby enhance crop production.

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World food needs call for more fertilizer[1]

By

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"Food will win the war" was an American slogan which paid off during World War II. "Food for Peace" is a recent American slogan that is more than a simple trio of words. Hungry people will not sit quietly while large numbers starve and die. Even people of high moral integrity, if there is no alternative, will steal from others more fortunate. Nationally, this leads to war.

The record shows that in the United States, prior to about 1940, we had not appreciably increased the per acre yields of the principal farm crops. Increased total production was due entirely to the development of new lands, to increases in acreage under cultivation. World War II, starting in Europe in 1939, brought about, as war always does, a sudden demand for more agricultural production but new land was no longer readily available. Greater yields became the only alternative. American farmers, with two incentives that have always worked, patriotism and high prices, showed that with proper tools and some "know how" they could produce the necessary food. Since 1940, yields of many crops have been gradually rising.

Records in Michigan are similar to those for other states. Corn and sugar beet yields have more than doubled. Wheat yields have increased by 50 percent. Appreciable increases have been recorded for most crops.

Workers in nearly all agricultural fields can share the credit for these increases. Improved varieties, the wide use of pesticides, and improved cultural practices have played their part but perhaps the leading single factor has been the greatly expanded use of commercial fertilizers. If it was not for commercial plant foods, the people of the United States would not today be enjoying their present high standard of living. Six percent of them would not today be feeding the other 94 percent. Many would be practicing subsistence farming on land now idle or being used for purposes other than agriculture, recreation and forests.

There are many countries today where fertilizers are scarcely used, and where few or no research data exist regarding its use. In even more countries, soil testing is unheard of. In Michigan, we can give a farmer a good fertilizer recommendation today because we can test his soil, and because we have a history of field experimentation with which we can evaluate the individual soil test figures (2). India is fast developing soil test laboratories. Dr. Roy Donahue, formerly with Ford Foundation in New Delhi, has pointed out how soil testing and proper use of fertilizers can help Indian farmers get more from their investment (1). Yes, commercial fertilizer will play an important role in the

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greatest success story of all time, that of world food production in the next 33 years.

Michigan farmers have increased fertilizer use by more than 10 times in the last 3 decades. Soil tests show that phosphorus levels have been greatly increased in many farm soils. This is especially true where sugar beets or potatoes are regularly grown. As determined by extraction with 0·025 N HCl + 0·03 N NH_4F (soil solution ratio of 1 to 8), levels of 100 to 200 pounds of phosphorus per acre are common. According to all field fertility—soil test correlation studies, such values are very high and reflect accumulations from applied fertilizers, referred to in our reports as residual phosphorus.

Until recent years in Michigan, we thought we could not cause damage with excessive applications of phosphorus. We were wrong ! Excessive phosphorus induces zinc and/or iron deficiency in plants to the extent of depressing yields. In this paper we illustrate by presenting a few data to show the effect of zinc and in 1966, iron, on the yield of white pea beans. The role of phosphorus in the soil and/or fertilizer is clearly evident.

Experimental

White pea beans (Phaseolus vulgaris) were planted in 1964 on a clay loam soil where variable amounts of phosphate fertilizer had been plowed under during a previous year. Variable rates of zinc were applied as three chelates, EDTA, NTA, and HEEDTA. These materials were compared with zinc applied as a powdered oxide or as zinc sulfate.

The data (reported in Table 1) show clearly that high levels of residual phosphorus in the soil had the effect of inducing zinc deficiency in the bean plants. Zinc tests show that this soil is quite low in amount of this nutrient. The yield of beans where phosphorus had not been plowed under was increased by 3·6 bushels per acre by an application of 0·9 pound of Zn chelate (average of the three materials) per acre. This was a significant indication that the low soil test for zinc was real.

Now look at the response of the crop to zinc where there were large amounts of residual phosphorus and where soil tests had been raised above the 36 pound level usually considered as a dividing point between low and high. As shown by the data in Table 1, the yield without zinc was 10·7 bushels an acre. The average obtained where the three chelates were applied at 0·9 pound was 24·5 bushels an acre. This is a very significant increase, 13·8 bushels an acre as compared to 3·6 bushels where the soil contained no residual phosphorus. Zinc applied as the powdered oxide or as the sulfate, each at 3 pounds per acre, was not quite as effective as the average of the chelates applied at the rate of 0·9 pounds per acre.

Data from a clay loam soil in 1966 are presented in Table 2. Phosphorus was applied at rates of 32 and 64 pounds per acre, respectively. The data show that, without zinc, an application of 32 pounds of phosphorus in a band close to the seed caused a significant reduction in yield of beans and the larger application caused a complete yield failure. Early growth and zinc uptake were not affected.

Where zinc was mixed with the fertilizer, both phosphate applications actually increased yield of the mature beans as well as growth of the 5-week-old plants. Zinc uptake was also greatly increased by zinc in the fertilizer.

TABLE 1

Yield of pea beans as influenced by zinc (variable carriers and rates of application) and variable rates of phosphorus applied as fertilizer during a previous season

Zinc treament: Pounds zinc per acre	Carrier	Phosphorus treatment and soil test: 0 lbs* 19 lbs**	87 lb* 31 lbs**	174 lbs* 44 lbs**	348 lbs* 75 lbs**	696 lbs* 144 lbs**
		bu/acre	bu/acre	bu/acre	bu/acre	bu/acre
0	–	27·9	30·9	22·1	16·7	10·7
0·3	EDTA-Zn	27·2	24·2	23·6	21·1	14·2
0·6	EDTA-Zn	25·8	24·2	25·3	23·1	21·2
0·9	EDTA-Zn	33·0	26·2	30·6	27·5	26·2
1·2	EDTA-Zn	27·2	23·9	25·2	27·5	26·4
0·3	NTA-Zn	25·6	31·2	23·6	20·6	10·1
0·6	NTA-Zn	31·2	27·9	24·4	23·9	17·0
0·9	NTA-Zn	31·0	29·0	29·6	28·1	20·0
0·3	HEEDTA-Zn	29·2	28·4	27·0	24·1	22·2
0·6	HEEDTA-Zn	29·7	28·9	27·3	26·0	24·7
0·9	HEEDTA-Zn	30·6	30·0	30·7	30·3	28·2
3·0	ZnO(powder)	27·5	25·1	23·1	22·0	17·6
3·0	$ZnSO_4$	29·0	27·0	28·7	27·2	19·0

Planting time fertilizer was at the rate of 200 pounds of 6-24-12, plus 4 pounds of manganese, per acre. The zinc carriers were mixed with the planting time fertilizer.

*Pounds phosphorus plowed under during previous years.
**Soil test for phosphorus during current season.

A comparison of two zinc carriers and two iron carriers was made on the same soil as the one used for the study reported in Table 2. The planting time fertilizer contained 42 pounds of phosphorus and was applied in a band close to the seed.

TABLE 2

Plant weights and zinc uptake by five-week-old plants and yield of pea beans as affected by the phosphorus content of the planting time fertilizer

Zinc treatment	Planting time fertilizer*: lbs. P/A	lbs. N/A	Plant weight: gms/10 plants	Zinc uptake: mg Zn/10 plants	Yield dry beans
0	0		6·8	·10	7·6
0	0	38	11·0	·17	20·7
0	32	38	12·4	·17	14·8
0	64	38	10 2	·14	0
3	0	38	11·0	·17	20·7
3	32	38	20·5	·43	27·4
3	64	38	23·3	·57	27·3

*The fertilizer was placed in a band 1 inch to the side and 1½ inches below the seed. The soil is clay loam with pH 7·4, low in zinc and high in available phosphorus.

Zinc sulfate applied at the rate of 3 pounds per acre greatly increased the growth of young plants and the uptake of zinc (see Table 3). It also increased the yield from 8·4 to 11·5 bushels per acre. Iron sulfate, similarly applied, was not very effective. Applied as a chelate, however, iron was very effective as was also zinc applied as a chelate. The highest yield of dry beans came from applying the two chelates together. The lower rate of 0·3 pound each was sufficient in this particular trial but in other experiments there was evidence that 0·6 to 0·9 pound of zinc in the chelate form is needed.

TABLE 3

Plant weights and zinc uptake by five-week-old plants and yields of pea beans as affected by various zinc and iron carriers on clay loam soil

Treatment*					Yield
Zinc	Iron	Carrier	Plant weight	Zinc uptake	per acre
Lbs.	Lbs.		gms/10 plants	mg/10 plants	bu.
·0	0		6·5	·08	8·4
	10	$FeSO_4$	8·9	·11	5·8
3·0	–	$ZnSO_4$	23·1	·36	11·5
0·3	–	ZnNTA	19·3	·27	22·6
0·6	–	ZnNTA	24·5	·38	23·8
0	0·3	FeNTA	16·2	·23	18·1
0	0·6	FeNTA	17·0	·22	26·5
0·3	0·3	Zn & FeNTA	24·3	·39	28·0
0·6	0·6	Zn & FeNTA	27·1	·57	29·2
0·6	0·3	Zn & FeNTA	28·3	·54	29·8
0·3	0·6	Zn & FeNTA	25·1	·45	30·2
0·6	6·0	ZnNTA & $FeSO_4$	32·4	·61	24·6

*8-32-16 fertilizer at the rate of 300 pounds per acre (42 pounds phosphorus) was applied 1 inch to the side and 1½ inches below the seed. The soil is low in zinc and high in available phosphorus.

Summary

World usage of fertilizers has increased rapidly during the last three decades. It must continue to increase if the people of the world are to avoid mass starvation during the next equal number of years. Perhaps in some areas the great need for food may lead to excessive use of fertilizer. This was the case with phosphorous fertilization of white pea beans (Phaseolus vulgaris) in Michigan until it was discovered that under certain soil conditions, an application of zinc was necessary where heavy rates of phosphate fertilizer was to be used and/or where residual soil phosphorus levels are high. In one experiment in 1966, similar results were obtained also with iron. As fertilizer usage is extended to the limit, these and other micronutrient deficiencies will become evident. We must keep plant nutrient supplies in balance if top yields and quality of product are to be obtained. This can be accomplished by the correlation of accurate soil tests with judicious use of plant nutrients.

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Les Phosphates Naturels – Facteurs Biologiques de Fertilite

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L'importante consommation des engrais phosphorés minéraux et organiques met bien en relief l'influence des teneurs en phosphore assimilable sur le niveau de fertilité des sols. Mais l'efficacité de ces engrais dépend de facteurs complexes et le taux d'utilisation par la plante du phosphore incorporé reste souvent très bas. L'apport de phosphore au sol pose donc de sérieux problèmes économiques et, dans la gamme des fertilisants disponilbes, les phosphates naturels bruts ont, de ce fait, conservé un large domaine d'application. Une évaluation aussi précise que possible de l'étendue de leur action et des conditions de leur efficacité doit contribuer à une meilleure utilisation des ressources naturelles. Ces conditions n'ont pas toujours été clairement comprises parce que les transformations subies par ces phosphates naturels faiblement solubles avant d'être assimilés par la plante sont mal connues. D'une manière générale, l'application en champ a donné de meilleurs résultats en sols acides (Thompson 1952, Schwartz, Varner & Martin 1954), mais elle peut être rentable en sols neutres ou peu acides (Meyer 1949, Barbier & Tendille 1958) car elle exerce ses effets sur plusieurs récoltes successives (Cooke 1958) L'influence du taux de matière organique a été d'autre part établie et le rôle de la microflore du sol dans la transformation des minerais bruts est apparu primordial, comme Stoklasa l'avait pressenti dès le début de ce siecle et comme Gerretsen (1949) en particulier l'a bien démontré.

Un autre aspect des relations entre la fertilisation phosphatée et la biologie des sols a été trop souvent négligé : c'est l'action stimulante de ces phosphates sur l'activité de la microflore du sol, qui est elle-même fréquemment limitée par la teneur en phosphore assimilable. On doit pourtant tenir compte de cette action pour évaluer avec certitude l'accroissement de fertilité qui peut être attendu d'une application de phosphates naturels dans des sols de caractéristiques différentes.

Nous nous proposons de signaler ici quelques résultats intéressants de ce point de vue, obtenus au cours d'une étude systématique des interactions entre phosphates naturels el microflore du sol. (Tardieux-Roche, 1966).

1). La stimulation de la microflore des sols par les phosphates naturels.

L'addition de phosphates naturels stimule la microflore du sol même lorsuque la teneur en phosphore assimilable n'est pas nulle. Nous avons pu démontrer au laboratoire cette stimulation par des mesures d'activité globale ou par dénombrement de la microflore totale et des principaux groupements physiologiques. Cinq échantillons de phosphates naturels provenant d'Afrique du Nord, de Floride et de la péninsule de Kola ont été incorporés à divers échantillons de sols de faible teneur en phosphore assimilable. L'émission de CO_2 a été mesurée au cours d'une période d incubation de 15 jours à 28°C et à un taux d'humidité correspondant aux 2/3 de saturation. Les dénombrements de microorganismes ont été effectués à la fin de cette période. La figure 1 montre le dégagement de CO_2 dans un échantillon incubé en présence et en absence de phosphates naturels. Des figures analogues ont été obtenues avec les autres échantillons. Le tableau 1

exprime les résultats du dénombrement de la microflore totale dans 2 terres en présence de 5 phosphates. Nous avons comparé l'effet de stimulation exercé par une même qualité de phosphate sur les différents échantillons de sols et inversement l'effet des différents minerais sur la microflore d'un même sol. Les coefficients de stimulation pour le phosphate de Gafsa (P. A.) se situent entre 1,7 et 6,5 si l'on considère la production cumulée de CO_2 en 15 jours et entre 1,3 et 9 si l'on considère l'accroissement de la population microbienne globale. L'action des phosphates varie donc d'un sol à l'autre mais son amplitude ne peut être reliée à aucune des propriétés physico-chimiques étudiées et, en particulier, ni au pH ni à la teneur en phosphore assimilable. Elle parait donc dépendre essentiellement de la nature de la microflore portée. Les différentes qualités de phosphate ont une action de même sens aussi bien sur l'émission de CO_2 que sur l'accroissement de la population maiselle est plus ou moins accusée ; l'ordre d'efficacité correspond en général à l'ordre de solubilité dans l'acide lactique à 2 pour cent.

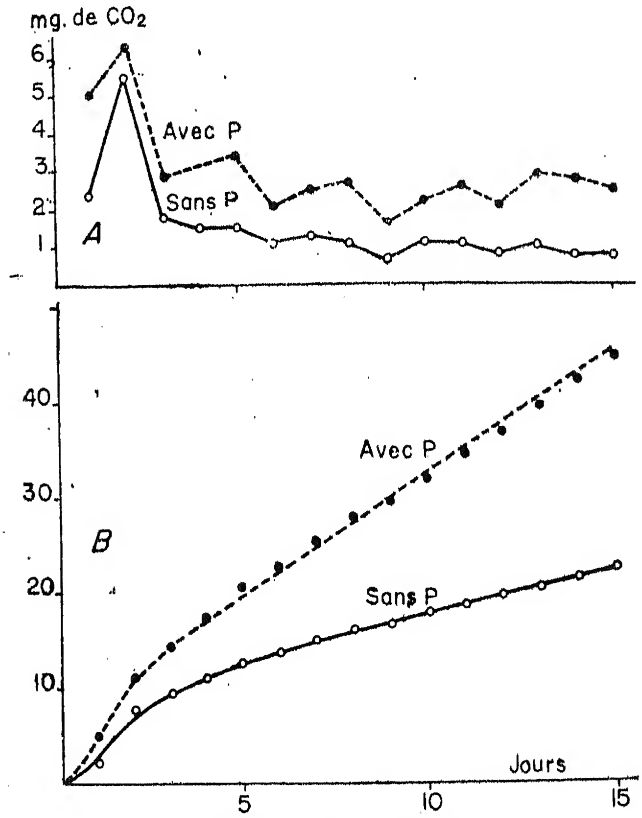

fig.1 - TERRE V Dégagement de CO_2
A) taux journalier *B)* taux cumulatif

L'étude des groupements fonctionnels des cycles de l'azote et du carbone a permis de reconnaître parmi les grandes fonctions de la microflore les plus sensibles à l'apport de phosphate. Ce sont essentiellement les fixateurs de l'azote aérobies, les nitrificateurs, les cellulolytiques aérobies qui sont l'objet d'une stimulation préférentielle. Les coefficients de stiumlation observés s'étagent de 20 à 68 pour les *Azotobacter*, de 2 à 10 pour les *Nitrosomonas* et pour les cellulolytiques.

Nous n'avons, dans cette étude considéré que le nombre de cellules viables. L'activité biochimique peut être stimulée dans des proportions plus importantes encore comme Dhar (1958) l'a montré pour la fixation d'azote.

2). Modalités d'action de la microflore sur les phosphates naturels.

Beaucoup d'organismes du sol exercent sur les phosphates naturels une action de dissolution qui peut être mise en évidence sur des milieux de culture artificiels convenables additionnés de ces phosphates. Ces organismes représentaient dans nos échantillons de 1 à 35 pour cent de la population totale et constituaient des populations de 500 000 à 70 millions par gramme de sol. Parmi les diférents facteurs étudiés : végétation, pH des sols, teneur en matière organique, teneur en argile et teneur en phosphore assimilable, seule la nature du couvert végétal parait exercer une influence sur l'importance de ces populations, favorisées par les cultures de légumineuses nettement plus que par celles de graminées. Mais dans l'ensemble, tous les sols paraissent bien pourvus en organismes capables de Dissoudre les phosphates naturels. Cette propriété d'ailleurs ne peut être reliée à des caractères physiologiques spécifiques d'un groupe particulier de bactéries. Parmi les organismes les plus actifs que nous avons isolés, nous avons trouvé des espèces bactériennes très diverses appartenant à 9 generes d'Eubactéries : *Pseudomonas, Alcaligenes, Achromobacter, Agrobacterium Aerobacter, Escherichia, Erwinia, Brevibacterium* et *Bacillus*.

La majorité de ces organismes produisent lors du métabolisme des sucres une certaine quantité d'acides organiques et du CO_2 ; la dissolution des phosphates autour de leurs colonies peut être reliée à l'acidification du milieu. De même, dans les cultures en milieu liquide, l'élévation de la teneur en phosphate dissous résulte presque toujours d'une production d'acides. Cependant, elle n'est pas proportionnelle à la baisse du pH et il a été montré experimentalement qu'elle dépendait pour une large part du pouvoir chélateur des acides organiques élaborés. Dans certaines cultures, des métabolites intermédiaires tels que l'acide 2-cetogluconique, qui ne s'accumulent pas dans le milieu, peuvent faciliter l'assimilation des ions phosphates à partir de sources très faiblement solubles, en agissant dans le micro-environnement des cellules autant par chélation que par acidification. D'autres systèmes chélateurs peuvent etre produits par les bactéries et ainsi l'assimilation des phosphates naturels est possible par une très large proportion de bactéries du sol. Nous avons constaté à plusieurs reprises que diverses espèces non acidogènes absorbent autant ou plus de phosphate dans un milieu où il est fourni sous forme d'apatite que dans le meme milieu contenant un mélange de phosphates solubles. Il en résulte une accumulation de phosphore dans les cellules. Nous l'avons étudiée spécialement dans deux bactéries isolées du sol et par différentes techniques de cytochimie ainsi que par le fractionnement du phosphore cellulaire, nous avons pu constater qu'une grande partie de celui-ci se trouvait sous forme de phosphates condensés.

La presénce de polyphosphates dans les cellules vivantes est un fait maintenant bien établi pour une grande variété de microorganismes mais la propriété

de former et d'accumuler ces corps en quantités représentant une fraction importante du poids sec des cellules paraissait caractériser quelques genres seulement (*Corynebacterium*, *Mycobacterium*). Elle est, en réalité, largement répandue et l'importance de la synthèse de phosphates condensés dépend surtout des conditions de nutrition comme l'a montré Harold (1963). Elle est liée au ralentissement des synthèses des acides nucléiques dans des cellules disposant encore d'un substrat énergétique utilisable. Nous avons pu, de notre côté, confirmer ces résultats en précisant les circonstances d'apparition des polyphosphates dans des bactéries du sol. L'accumulation de ces polymères dans les cellules ne prend d'importance que lorsque la concentration extérieure en phosphate dissous est maintenue faible, le renouvellement des ions phosphoriques assimilés étant pourtant assuré. Cette éventualité est réalisée dans les cultures expérimentales en présence d'apatite comme seule source de phosphore et les conditions de milieu sont alors analogues à celles que rencontrent fréquemment les bactéries dane le sol et spécialement dans la rhizosphère des plantes.

TABLEAU I

Indexation des échantillons de phosphate	Terre III		Terre V	
	Nombre de germes par g. de terre	Nombre de germes de la terre + P / Nombre de germes de la terre sans P	Nombre de germes par g. de terre	Nombre de germes de la terre + P / Nombre de germes de la terre sans P
sans P	$5 \cdot 10^6$		$35 \cdot 10^6$	
P . A	$45 \cdot 10^6$	9	$70 \cdot 10^6$	2
P . B	$35 \cdot 10^6$	7	$70 \cdot 10^6$	2
P . C	$17 \cdot 10^6$	3,4	$50 \cdot 10^6$	1,7
P . D_1	$12 \cdot 10^6$	2,6	$35 \cdot 10^6$	1,0
P . D_2	$11 \cdot 10^6$	2,2	$45 \cdot 10^6$	1,1

Influence de différents phosphates sur la microflore totale de deux terres.

Discussion et conclusions

L'efficacité des phosphates naturels utilisés comme engrais a été souvent comparée à celle des autres formes de fertilisants phosphorés avec des résultats variables suivant la nature des cultures pratiquées et les conditions du sol. L'accroissement de fertilité lié à leur emploi ne doit pas être jugé seulement per l'amélioration immédiate des rendements de culture. Il résulte en effet pour une large part de mécanismes indirects dont le déroulement se prolonge bien au-delà de la première récolte. La microflore du sol se trouve étroitement impliquée dans leur mise en oeuvre.

Dans des sols pauvres en phosphore assimilable, les microorganismes et les plantes sont en compétition pour cet élément. Le développement des uns et des autres se trouve limité et l'activité restreinte des groupements fonctionnels de la microflore, dont dépend en partie la nutrition de la plante, retentit secondairement sur elle. Nos observations montrent que la population microbienne peut être sérieusement limitée bien avant que toutes les ressources du sol en phosphore assimilable aient été épuisées. Le sol, en effet, est un milieu très hétérogène surtout à l'échelle des microorganismes. Il ne leur offre qu'une juxtaposition de microhabitats différant profondément les uns des autres par les conditions de nutrition réalisées. Le défaut de phosphore dans un microhabitat n'est pas compensé par un excès dans un autre où la croissance se trouvera limitée par un autre facteur. C'est ainsi que le tamisage, l'homogénéisation et la réhumectation d'échantillons de sols carancés en phosphore suffisent à provoquer un regain appréciable de l activité biologique, mais de courte durée. L'apport de phosphates naturels accentue fortement et prolonge cette stimulation et cet effet peut s'interpréter par une multiplication du nombre de microhabitats où l'approvisionnement en phosphore est convenablement assuré.

Tous les groupes de microorganismes ne répondent pas d'égale façon à cet enrichissement. Il est particulièrement significatif que les groupements fonctionnels attachés aux étapes les plus décisives pour la fertilité du sol des cycles du carbone et de l'azote soient les plus stimulés : fixateurs d'azote, nitrificateurs, cellulolytiques aérobies. La production de nitrates, de substances de croissance, la synthèse de matériel humique qui en résultent améliorent les conditions de végétation à la fois dans l'immédiat et à échéance.

L'assimilation des phosphates par la microflore du sol est le point de départ de cette reprise d'acitivités favorables. Elle est en même temps la première étape de la mobilisation du phosphore à partir de formes insolubles. Ce phosphore assimilé par la population microbienne, "immobilisé" suivant la terminologie classique, est en réalité beaucoup plus facilement accessible aux plantes que le minerai d'origine. Dans les sols où les conditions d'une dissolution directe par les acides de fermentation ne sont pas réunies, le phosphore cellulaire peut apparaitre comme un intermédiaire nécessaire entre les phosphates insolubles et les ions phosphoriques absorbés par la plante. De ce point de vue, l'accumulation des phosphates inorganiques condensés par une partie de la micropopulation est un facteur dont on ne peut encore mesurer l'importance. C'est un processus rapide et nous avons montré que les conditions de sa mise en oeuvre se trouvaient assez bien réunies dans le sol et notamment dans la rhizosphère des plantes.

La dissolution des phosphates naturels à ce niveau peut donc être comparée à la minéralisation de la matière organique : celle-ci peut, soit être convertie directement en formes minérales assimilables par les plantes, soit former un humus stable dont la minéralisation sera progressive. De même, la dissolution des phosphates par les acides d'origine biologique, excrétés par la plante ou les microorganismes, libère directement des ions phosphoriques assimilables tandis que le phosphore accumulé dans les cellules microbiennes constitue une réserve analogue à l'humus. Dissolution et assimilation ne s'opposent pas, au contraire, le premier processus favorise le second et les deux sont stimulés par les mêmes facteurs, apport de matière organique, effet rhizosphère, et, notamment celui des légumineuses.

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Higher constancy of yields effected by amply dressing with nitrogen and phosphorus

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Crop yields are considerably increased by dressing with nitrogen and phosphorus on soils being deficient in these elements. However, this is not the only advantage of fertilizing for the economy and political stability of a country. It is of highest importance that ample fertilization also tends *to level off yield fluctuations.*

Some examples of the latter will be given, and it will be tried to elucidate why fertilization causes a higher constancy of yields.

Nitrogen response of rye and potatoes.

A nitrogen-crop rotation field trial has been conducted since 1947 on a soil with a high content of humus. Such a soil is able to provide the crop with about half of the amount of nitrogen required for maximal yield. Potatoes (Voran) and rye have been grown in rotation, each crop being represented annually on one of the halves of the experimental field. Of both crops 19 yields have been gathered. Nitrogen was applied in increasing amounts and nitrogen yield curves have been drawn for each year (3). From these curves yields at any arbitrary dressing could be deduced, but only yields obtained with 0,50 and 100 kg nitrogen per hectare (rye) and with 0, 80, 200 kg potatoes) have been used. The average annual yields with their standard deviations are given in table 1.

TABLE I

Average annual yields (in 100 kg per ha) and standard deviations in percentages at different levels of nitrogen dressing.

Crop	av. Yields			av. Standard deviation %		
	0	50 (80)	100 (200)	0	50 (80)	100 (200)
Rye (grain)	24,1	33,5	39,8	20,1	15,2	14,1
Potato (tubers)	333	406	442	15,6	11,5	12,0

Nitrogen dressing has given rise to a considerable increase of yields and has decreased the standard deviations. The large variability of yields of rye not dressed with nitrogen has to be attributed mainly to differences in the amounts of residual nitrogen present in the soil within the reach of the roots. Usually a stock of soluble nitrogen is built up in the autumn by mineralization of organic matter.

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It depends on the intensity of rainfall in October/February (1) which part of this stock will remain available.

The largest difference in available nitrogen in early spring was found to amount to about 75 kg nitrogen per ha. This amount was present after a dry winter. On the other hand all nitrogen was lost by leaching in very wet winters. This difference is of considerable importance for a winter cereal developing in a cold soil with low rate of nitrogen mineralization.

For the plots without nitrogen dressing the variance of rye yields could for 87% be explained by the differences in the sum of rainfall during the period mentioned. This percentage decreases to 70% for a dressing with 50 kg nitrogen per ha, to 33% with 75 kg (being an average dressing) and to 8% with 100 kg of nitrogen (fig. 1).

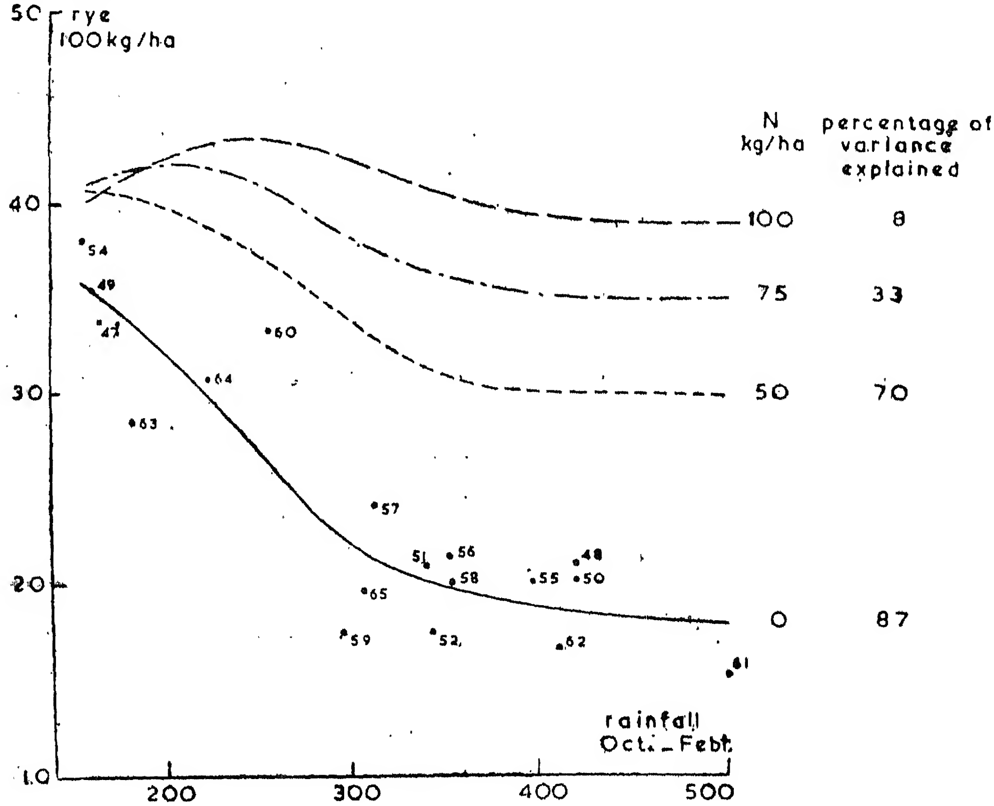

Fig. 1. Effect of winter rainfall (October till February) on grain yield of rye at 3 levels of nitrogen dressing.

As a matter of fact dressing with nitrogen after a wet winter on a soil very poor in this element in an available form will have a more significant effect on the yield than on a soil after a dry winter liberally provided with nitrogen by a residue from the preceding year. This explains the levelling effect of nitrogen found with rye in this case.

For late industrial potatoes the residual nitrogen is less important. Only 14% of the variance of tuber yields harvested without nitrogen dressing could be explained by differences in winter rainfall. Additional rainfall in March/May (June) may alter the amount of residual nitrogen. Moreover, the significance of the contribution of nitrogen mineralization to the nutrition of the plant is greater in the case of potatoes than in that during the vegetation period of rye. For the latter the mineralized nitrogen becomes available only in a later phase of growth. For potatoes on the contrary, it is available from the beginning and nitrogen, mineralized in a later period of the season, can also be utilized. It was found on this soil that the amount of nitrogen in the soil becoming available to the crop by mineralization corresponds on an average with 150 kg per ha for potatoes and with only 90 kg for rye (3).

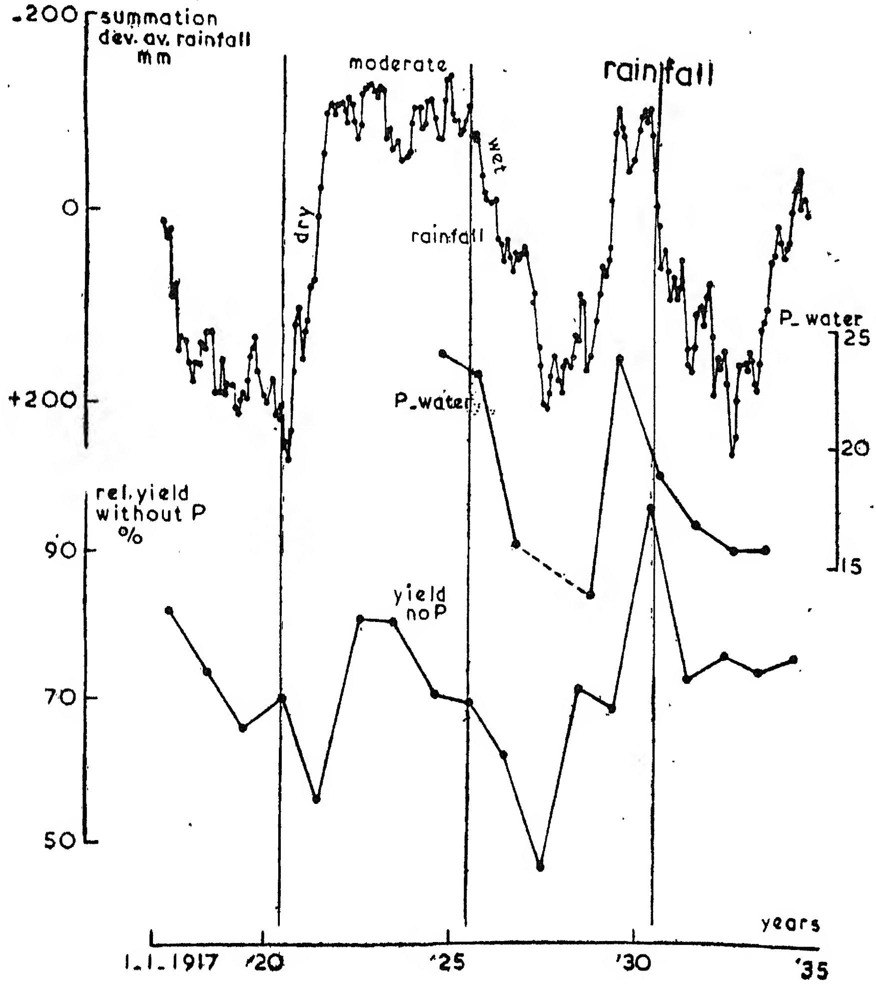

Fig. 2. Fluctuations of relative yields of potatoes grown without phosphorus dressing in percentages of those with complete dressing compared with fluctuation of the content of water-soluble soil phosphorus and with part of a summation curve of the deviations of average monthly rainfall.

It follows that potatoes grown without nitrogen dressing, in comparison to rye, are more amply provided with nitrogen. This is especially the case after a wet winter. Consequently potatoes are less sensitive to the fluctuations in the amount of available soil nitrogen in the spring because this factor is only partly limiting. The reduction of the variance achieved by nitrogen dressing must mainly be attributed to differences in nitrogen mineralization, which hardly affect the yields obtained with a sufficient supply of nitrogen. These differences in nitrogen mineralization seem to be connected with the pattern of rainfall distribution over years. During a series of wet years the amount of nitrogen annually mineralized decreases steadily (2, 4). The still considerable fluctuations of the yields of crops well supplied with nitrogen have partly to be attributed to fluctuations of other fertility factors. It has been suggested that the influence of the rainfall pattern on the conversion of soil organic matter is playing an important role hereby (4).

Phosphorus response of potatoes.

The discussion will be limited to potatoes grown with and without phosphorus dressing on the first field trial conducted in the Netherlands. It was started in 1881 on a soil very rich in humus. From 1916 onward industrial potatoes (Thorbecke) and cereals have been grown alternately on the two halves of the field.

It was found that the yields without phosphorus dressing, expressed in percentages of those obtained with complete dressing, paralleled the fluctuations of the amount of available soil phosphorus. It appeared that the fluctuations of the latter were induced by those of the rainfall (fig. 2). In this figure the distribution of rainfall is shown by a summation curve. Deviations from the average monthly rainfall (determined for each month separately) in the period 1880-1958 have been summed up. A rise in the curve in figure 2 indicates a period with rainfall being below the average, a drop one with rainfall above normal. Alternating dry and wet periods can be distinguished. The course of the P-water value (a reliable measure of available phosphorus) proves to parallel that of the rainfall curve. This means that the availability of soil phosphorus was falling in period of wet years and rising in dry years. The average yields of potatoes and their standard deviations are given in table 2.

TABLE 2

Mean annual yields of potatoes (in 100 kg per ha) and their standard deviations without and after elimination of trends.

av. Yields		Standard deviations %	
NK	NKP	NK	NKP
226	305	31,6	26,2
		after elimination	
		25,0	16,3

It is plausible that the higher standard deviation of the plots without phosphorus dressing is due to the fluctuations of the content of water soluble phosphorus; which must be considered a growth limiting factor.

The inadequacy of the decline of the standard deviation to account for the stabilizing effect of fertilization.

Thus far, the higher constancy of the yields on amply dressed plots has been proved by their lower standard deviation. However, the standard deviation reflects not only the differences in the amounts of available growth factors ; it includes all inevitable "errors". Therefore, the stabilizing effect of an amply dressing is not properly demonstrated by the reduced standard deviation. The experimental errors are especially important in the phosphorus experiment performed in a primitive way and without replicates. The aforementioned fact obscures the fertilization effect. A rectilinear rising trend in the yields of the phosphorus experiment in the period 1916-1934, probably due to the agricultural improvement of the experimental field (increased fertilization, better quality of seed potato, etc.) has considerably contributed to the height of the standard deviation. After elimination of this trend much lower standard deviations were found (table 2) and the difference between fertilized and unfertilized plots become more pronounced.

Nevertheless, the effect of other unknown factors is still included in the corrected standard-deviation. It may be concluded therefore, that quantitatively the stabilizing effect of fertilization is even more important than is apparent from a comparison of standard deviations.

Discussion

The annual variations of crop yields are makedly decreased by regular applications of nitrogen or phosphorus. It has been demonstrated that the effect might be greater than can be deduced from a comparison of the height of standard deviations.

Different causes have been indicated. They have in common, however, that in all cases fluctuations of the intensity of sharply limiting factors were induced. Relatively slight variations of limiting factors (N and P) give rise to strong fluctuations of yields on deficient soils. The inconstancy of yields is reduced when the effect of sharply limiting factors are eliminated by means of amply dressing.

This higher constancy of yields combined with a higher productivity, appears to be of fundamental interest for emerging countries with a dense population.

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Fertilisation des sols et Oligo-elements

par M. DIDIER BERTRAND - PARIS

D'après les statisticiens, la population du globe s'est augmentée de plus de 175 millions d'êtres depuis 4 ans et demi et si ce rythme d'accorissement des populations se poursuit, il y aura déjà plus de six milliards et demi d'hommes sur la terre en 1998. Or il ne faut pas oublier que près de la moitié des surfaces émergées de notre planète sont impropres à la culture et que sur le restant il n'y a que un milliard 125 millions d'hectares labourables, les autres pouvant être ou étant, utilisés comme paturages. En définitive, la nourriture actuelle de l'homme est tirée de deux pour cent seulement des superficies continentales. Il importe donc de les utiliser au maximum possible puiqu'à l'heure actuelle les deux tiers, déjà, des populations sont sous-ali-mentées.

Or, alors que les nutritions humaine et animale font l'objet de multiples travaux coordonnés pour aboutir à la recherche d'une alimentation rationnelle, équilibrée et rentable, il est loin d'en être de même en ce qui concerne les végétaux qui sont pourtant la base de cette alimentation.

Les quelques rares engrais que l'on consent à mettre sont trop souvent considérés non, comme des aliments indispensables, mais seulement comme des facteurs d'amélioration possible des récoltes (1). Les terres arables ne sont évidemment pas de simples supports et les végétaux qui y poussent doivent y trouver les constituants essentiels de leurs tissus, mais pratiquement jamais ils ne peuvent trouver ceuxci en proportions convenables et optimales.

En dehors de N, P, K, dont on se préoccupe parfois, on oublie trop souvent le soufre, le magnésium et surtout tous les constituants minéraux existant en très petite quantité, mais pourtant essentiels, car constituants des systèmes enzymatiques : les oligo-éléments. Or la déficience de ceux-ci au niveau des racines, ou l'augmentation des besoins crée par la présence dans le sol d'un élément antagoniste présent en grande quantité, peut entrainer une véritable stérilité de la terre, au moins pour les cultures sensibles, modifiant ainsi l'aspect du biotope. Dans ces cas là une operation très peu couteuse permet une culture qui si elle n'est pas optimale, faute d'uen quantité suffisante de N, P, K, entre autres, permet déjà néanmoins, une culture rentable qui représente un apport important. C'est ainsi par exemple, que certaines terres de récupération du Bas-Rhône, en France, terres acides, sont très pauvres en molybdène. Ces terres sont stériles pour beaucoup de végétaux. L'apport, d'au plus, quelques centaines de grammes par hectare de molybdate d'ammoniaque permet des cultures spectaculaires. Prenons d'autres exemples dans une région moins déshéritée : la région parisienne. On y trouve des terrains pauvres en magnésium. Sans l'addition d'engrais, la culture de carottes y fut en 1963, dans l'un d'entre eux, de 32, 2 tonnes par hectare. Après addition de seulement 0,75 K de magnésium par hectare (mis sous forme de sulfate) la récolte fut de 5,9 tonnes ; avec en plus une augmentation de taux de sucre et de carotène. Dans la même région et pour un terrain pauvre en molybdène, l'addition de 280 g de molybdate d'ammnium par hectare a suffit pour faire passer la récolte de luzerne de 5,7 tonnes à 9,3 tonnes par hectare.

(1) ni le probleme de l'eau, ni celui de l'ensoleillement, ne seront envisages ici.

Ce dernier exemple illustre bien un fait très important et pourtant totalement négligé dans l'enseignement traditionnel : si la déficience accentuée en un oligo-élément, qualifiée à tort de carence, entraine un aspect pathologique du végétal, une déficience moins grande n'entraine de visible qu'une diminution de récolte sans aucun signe pathologique qui puisse mettre en garde le praticien. Or ces déficiences sournoises conduisent en réalité à des pertes considérables pour l'économie mondiale et on doit s'en préoccuper d'autant plus qu'une culture intensive les accentue rapidement. Elles sont d'ailleurs rarement unique mais le plus souvent multiples. Lorsqu'on y remédie correctement, les rendements peuvent doubler et la qualité s'augmenter. Plus de 250 essais réalisés en champs dans les conditions de la culture normale, m'ont confirmé ce fait capital.

Comment déceler et comment remédier à ces déficiences en oligo-éléments ? En principe si une terre est pauvre en un oligo-élément donné ou bien si cet oligo-élément se trouve sous une forme insoluble, les végétaux qui y seront cultivés seront déficients en cet oligo-élément. L'analyse chimique de la plante et du sol devraient donc pouvoir nous renseigner. Fn réalité nous ignorons complètement comment les racines peuvent extraire du sol les éléments qui s'y trouvent et la physiologie suffit à nous prouver qu'il y a, à ce point de vue, de grosses, différences suivant les végétaux. C'est ainsi, que les graminées qui sont sont riches en silice, peuvent dissocier les silicates, et, de ce fait, croître sans manifestation de déficience dans des terres où le taux des oligo-éléments extractibles par une solution de pH neutre d'acétate d'ammonium est tellement bas, qu'à priori aucune culture n'y parait possible et en fait il en est bien ainsi pour d'autres végétaux tels que le melon, par exemple pour le cas précis du molybdène.

D'autre part, même dans une terre ou l'interprêtation de l'analyse reste correcte, on peut avoir des déficiences en certains oligo-éléments, déficiences entrainées par un déséquilibre minéral conduisant à une augmentation des besoins ou par un excès de phosphates pouvant bloquer certains oligo-éléments comme le zinc ou le manganèse. Inversement certains engrais peuvent par déplacement physico-chimique libérer plus d'un oligo-élément donné que ne le fait l'extraction par une solution d'acétate d'ammonium à pH neutre, par exemple. Enfin l'expérience prouve qu'une plante poussant sur un terrain riche en un oligo-élément peut présenter dans ses tissus un taux inférieur, en cet oligo-élément, par rapport à la même plante poussant sur un terrain où la concentration nutritive en cet oligo-élément est optimale. On conclurait donc trop vite, dans ces cas, à une déficience là où il y a un excès.

Il faut donc d'une part multiplier les analyses des sols comparées aux réponses expérimentales à l'addition d'oligo-éléments, de façon à trouver pour chaque type de terre et de culture, une technique conduisant à une bonne corrélation, et d'autre part savoir interpréter correctement les renseignements fournis, non seulement par cette analyse, mais aussi par la connaissance des engrais mis sur le sol.

Remédier à une déficience en oligo-éléments semble assez facile à priori. En réalité cette opération doit être soumise à un certain nombre de règles simples mais essentielles et impératives, si l'on ne veut pas aboutir à un échec.

La première qui est rarement prise en considération est celle de la loi de l'optimum de concentration nutritive. Loi démontrée théoriquement et vérifiée expérimentalement par de très nombreux exemples résultant d expériences de laboratoires ou faites en champs : un excès d'oligo-élément est nuisible. Il ne faut donc pas opérer suivant une technique du tout ou rien et ne pas dépasser un

optimum. Avec certains sols et quelques oligo-éléments, il peut y avoir blocage de l'excès, si bien que si l'on ne trace pas de courbe de réponse en fonction de la quantité d'oligo-élément ajouté, on pourrait croire à une loi type Mitscherlich. Il n'en n'est rien et il y a toujours un maximum. Mais si dans ces cas l'excès est peu nuisible, il arrive qu'il puisse l'être fortement et dans ces cas là, qui sont fréquents, si le sol est déjà suffisamment riche, l'excès d'oligo-élément ajouté inconsidérement conduit à une récolte plus faible que le témoin, résultat inverse de celui que l'on espère.

La dose optimale varie suivant la plante et suivant la façon dont l'oligo-élément est mis à la disposition de celle-ci. Prenons par exemple le cas du molybdène et d'une culture de légumineuse sur un sol pauvre en cet oligo-élément. On peut tremper les graines dans une solution de molybdate d'ammonium. Dans ce cas 10 à 20 grammes de molybdène par hectare suffisent. Mais seule la plus jeune plante en bénéficie et en outre seulement si la graine elle même est pauvre en molybdène. Il est préférable de répandre ce molybdate d'ammonium mis en solution, sur le sol. Il faut le mettre, alors, avant que la plante ne pousse et dans ce cas 100 à 150 grammes suffisent en général pour obtenir l'optimum. La plante va bénéficier de cet apport pendant plus longtemps que dans le cas précédent et la récolte sera meilleure. On peut aussi arroser les feuilles avec des solutions diluées. Mais cette opération qu'il faut répéter est couteuse et est très délicate car l'absorption par les feuilles est très forte et de ce fait difficile à mener à bien par un non spécialiste entrainé. On peut enfin utiliser un oxyde de molybdène, mais la répartition homogène est très difficile à obtenir et ici aussi, les réponses varient beaucoup suivant la nature des sols et l'hygrométrie. Si bien que cette façon de faire, séduisante théoriquement, l'est beaucoup moins en pratique. Si au lieu d'une légumineuse nous avions a faire à du maïs, la dose optimale serait beaucoup plus forte : environ dix fois celle des légumineuses lorsqu'on arrose le sol. Mais en raison des possibilités des racines du maïs, c'est seulement dans des cas plus rares qu'il faut employer cet engrais.

Pour remédier à une déficience reconnue en un oligo-élément donné, il ne faut donc par ajouter cet oligo-élément n'importe commet et en n'importe quelle quantité. Mais en outre il ne faut pas oublier que la déficience en un seul oligo-élément est assez rare et que de ce fait vouloir n'en corriger qu'une entraîne souvent d'autres déséquilibres.

A l'heure actuelle quand on cherche des engrais équilibrés, on a tendance à vouloir ne se préoccuper outre N, P, K, que S, Mg, rarement de Ca, B, Fe, Mn, Cu, Zn, et Mo et à oublier tous les autres oligo-éléments dont la liste n'est d'ailleurs pas close de façon certaine. Ce faisant on risque de ne pas avoir l'optimum de poids et de qualité. Des exemples récents avec Ni et Cr nous l'ont prouvé. Mais il peut y avoir plus : prenons le cas du sélenium. Dans le centre de la France, pour ne parler que de ce pays, il existe une maladie du veau qui est provoquée par une insuffisance du taux de sélenium des végétaux de ces régions et peut être guérie par une addition de sélenium à la nourriture. Or, les végétaux ne souffrent pas de déficience. On ne connait un autre exemple avec le cobalt.

Donc, dans la recherche d'une nourriture minérale équilibrée des végétaux, il ne faut pas oublier que ceux-ci servent définitive d'aliments aux animaux et à l'homme et que la composition des végétaux doit satisfaire leurs besoins, non seulement d'ailleurs en éléments minéraux, mais aussi en d'autres facteurs : vitamines, acides aminés, etc., dont la teneur varie beaucoup en fonction des taux d'oligo-éléments et sans que le poids de la récolte puisse en être beaucoup affectée.

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Fertilizers from Coal

By

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Indian soils are particularly deficient in nitrogen and as such supply of adequate amount of nitrogenous fertilizers have assumed paramount importance in the present food crisis the country is facing. According to agricultural scientists, a minimum dose of 30 lbs. of nitrogen per acre is to be recommended for Indian soils. At the same time the soil scientists have laid emphasis on the supply of adequate amount of organic matter to the soil. Application of organic manures in combination with commercial fertilizers appears to be almost indispensable for maintaining fertility of tropical soils.[1] It is not advisable to depend on fertilizers alone for augmenting the productivity of soils as tropical soils are, in general, deficient in organic matter.[2]

The application of dry and milled peat has been practised for centuries in various countries to increase the yield of crops. Its use in Ireland for growing potato is still prevalent. The application of lignite for soil dressing is widely practised in U. S. S. R. and in some of the Eastern European countries. The value of peat and lignite for agriculture arise from the fact that they are composed of humus which is an essential ingredient of all living soils. In India, deposits of peat are rare and lignite occurs only in some isolated places and the deposits are by no means extensive. However, there are extensive deposits of low rank coals in India. Researches carried out at Central Fuel Research Institute[3] have demonstrated that these can be easily converted to humic acids by comparatively inexpensive methods such as low temperature oxidation in air. Further, it has been observed that the properties and behaviour of these humic acids are similar to those occurring in fertile soils. It was, therefore, quite logical to suppose that the ideal nitrogeneous fertilizer for tropical soils, which are as a rule deficient in organic matter and nitrogen, should be nitrogen enriched humus. With the above objective in view, investigations have been conducted at CFRI for the past few years, to develop a class of fertilizers which should combine the properties of both humus or organic manure and nitrogenous fertilizers.

It is of interest to note in this connection that investigations were conducted in the past to prepare similar material in various countries,[4] but the subject largely remained of academic interest. Only in very recent times, industrial possibility of this type of fertilizers is being explored in all seriousness in U. S. A. and Japan.[5] However, the details of the processes are not available in print except as news items. But on the face of it, these processes are quite different from the one that has been developed at CFRI.

Preparation of Nitrogenous Organic Manure from Coal Humus

In the beginning, investigations were conducted with a view to developing a simple and inexpensive method for the production of humic acids from coal. It

was observed[8] that when coal reacts with air or oxygen at a moderate temperature (not exceeding 200°C) it is converted into a mass of acidic bodies called humic acids which are characterised by their solubility in alkalies and the presence in them of acidic functional groups such as carboxyl and hydroxyl. The humic acids readily react with ammonia and the product thus prepared is designated ammonium humate. It contains 5-7 p.c. nitrogen depending on the rank of coal used for the reaction and 4-6 p.c. nitrogen exists in readily soluble and available form as determined by standard A.O.A.C. method. The process described above had two serious limitations, namely, it is uneconomical as the oxidation of coal takes an unduly long time (50 60 hours) and the percentage of nitrogen in the product is very low. The method was subsequently modified to obviate these drawbacks. In the modified process, (Indian Patent No. 62337) the fertilizer is prepared by passing a mixture of air and ammonia gas through a bed of heated coal particles (325°C) maintained in a fluildized state by the reacting gases. Here, the reaction is complete within 4-6 hours and the percentage of nitrogen in the product varies from 12-20 depending on the condition of reaction and the rank of coal used. The fertilizer produced by this method has been designated *nitrogen-enriched coal* and it contains one third of the total nitrogen in an available state.

The process has since been developed on a semipilot plant scale in 3 inch and 7 inch diameter fluidization columns and a full scale pilot plant with a production capacity of 100 lbs. per hour has also been constructed recently. The production cost of the fertilizer as well as problems of scaling-up of the processes are under active investigation.

From the foregoing account, it is evident that this class of coal-fertilizers combine the properties of humus as well as synthetic nitrogeneous fertilizers. The vital role of soil humus on plant growth is well known. A detailed examination of the chemical properties of soil humus and coal-humus reveals that they are essentially similar colloidal complexes which are soluble in alkalies but insoluble in water or acids. Both are characterised by high base exchange and moisture holding capacities.

The properties and elemental composition of two types of coal-fertilizers used for field trials are presented in Tables 1 and 2.

TABLE 1

Ultimate analysis of ammonium humate (dry ash free basis)

C	- 63·42%	
H	- 3·20%	The product is
N	- 7·70%	soluble in water
S	- 0·30%	and alkalies.
O (by diffi.)	25·38%	
P. c. N available	5·5%	
(by A. O. A. C. method)		

TABLE 2

Ultimate analysis of nitrogen-enriched Product: (*dry ash free basis*)

C	-	66·1%
H	-	2·1%
N	-	18·3%
S	-	0·4%
O (by diff.)		13·1%

An idea of the distribution of nitrogen in the nitrogen-enriched product may be obtained from the following :

(*a*) P. c. N as ammonium salts (as obtained MgO distillation) = 0·76%

(*b*) P. c. N (released by acid hydrolysis) as amide, imide and nitrile = 3%

(*c*) P. c. N available by A. O. A. C. method = 6·5%

(*d*) By a process of elimination it appears that about 2/3 of the total nitrogen probably occurs in cyclic structures and this part of nitrogen is not readily available.

The value of a fertilizer is ultimately decided by its behavour under field conditions. Field trials were, therefore, conducted at two sites—namely at CFRI and at Marhand Farm, Hazaribagh—both being Chotanagpur loam soil[6]. Along with these, ammonium sulphate and an oil cake (5·5% N) were also used for a comparative study. The experimental layout at CFRI was of the Randomized Block type whereas at Hazaribagh it was Latin Square design. The plot size at CFRI was 17×4 ft. there being a total of 56 plots. At Hazaribagh, total number of plots were 25 and each was 25×25 ft. Two crops, namely, paddy in kharif and wheat in rabi, were grown with two doses of fertilizers. For paddy, 30 and 60 lbs. of nitrogen per acre were used and for wheat 20 and 40 lbs. at CFRI. At Hazaribagh, both paddy and wheat received 40 lbs. N per acre. Nitrogen-enriched coal was applied at the rate of 40 lbs., N per acre on total nitrogen basis as well as on the basis of available nitrogen. The different treatments were performed on the respective plots for all the crops. In addition, a basal dose of 40 lbs. of P_2O_5 as superphoshate and 20 lbs., of K_2O as potash chloride per acre were applied to all the plots at the time of starting the experiments.

Results and Discussion

The yields of paddy and wheat (grains and straw) in maunds per acre with respect to various treatments are recorded in Tables 3-8. The analysis of variance of the yield data of paddy and wheat showed that the treatments were significant both at 5 p.c. and 1 p.c. levels. The p.c. increase in the yield of crop and straw (compared to control) on continued application of different fertilizers is graphically presented in Figures 1-6. At CFRI, there was crop-failure for two consecutive years (1962 and 1963) due to draught condition and hence these data are not presented. In the period 1963-64, the overall yield of crop was uniformly poor in the entire region mainly due to adverse climatic conditions.

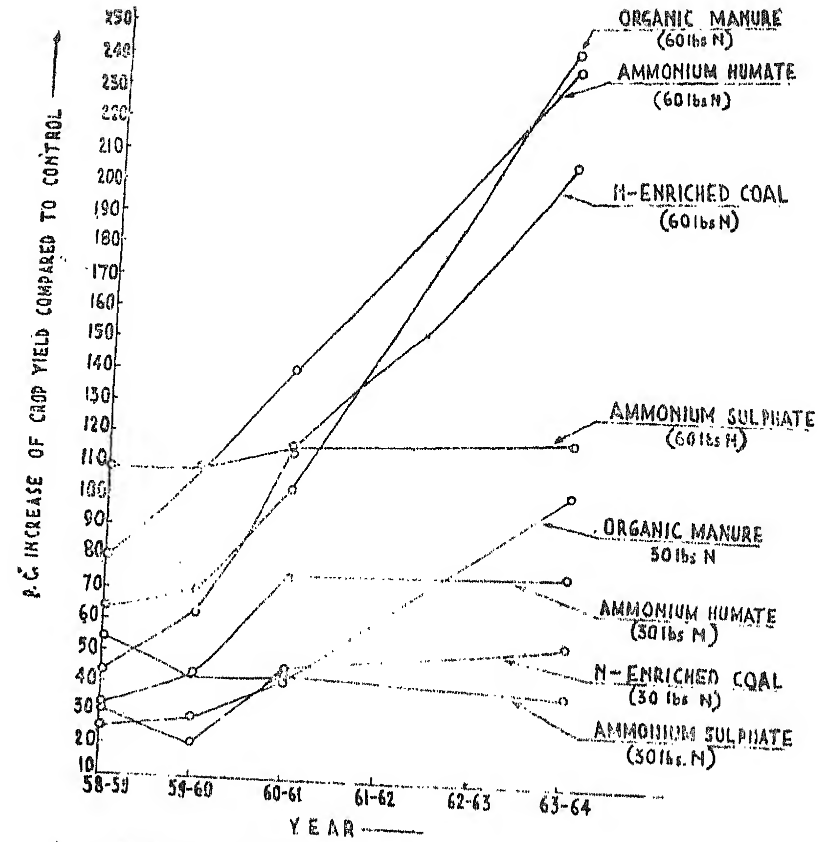

FIG. 1, EFFECT OF FERTILIZERS ON THE YIELD OF PADDY GRAIN (DHANBAD)

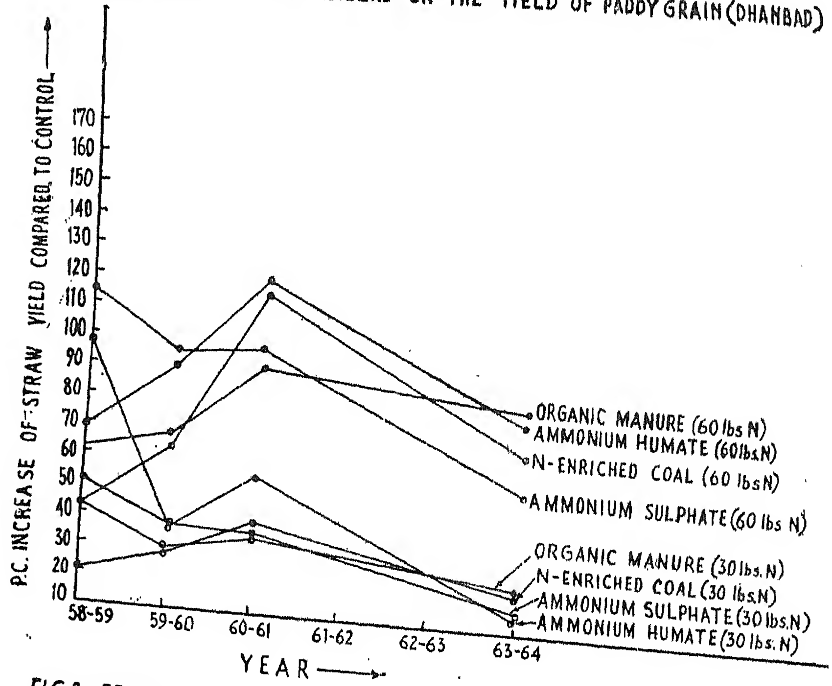

FIG. 2 - EFFECT OF FERTILIZERS ON THE YIELD OF PADDY STRAW (DHANBAD)

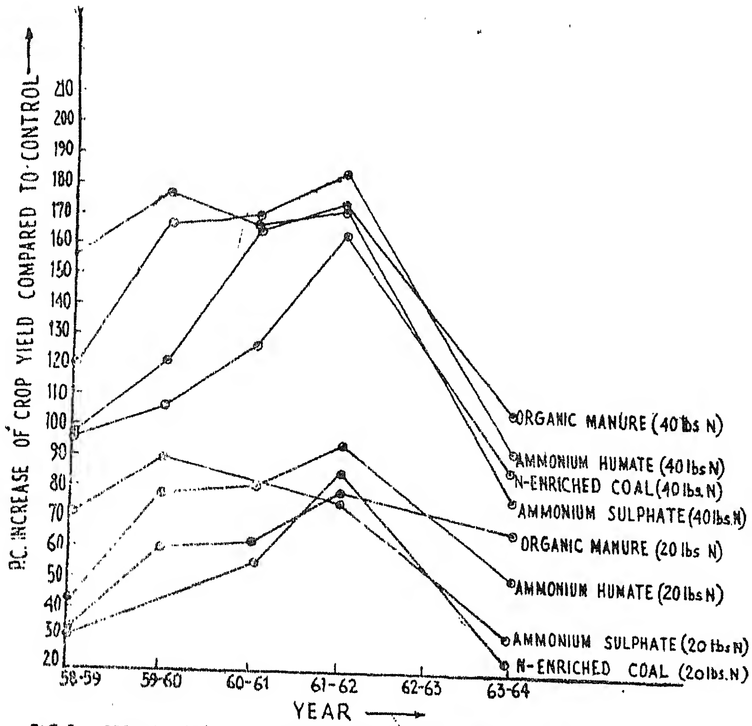

FIG. 3 - EFFECT OF FERTILIZERS ON THE YIELD OF WHEAT GRAIN (DHANBAD)

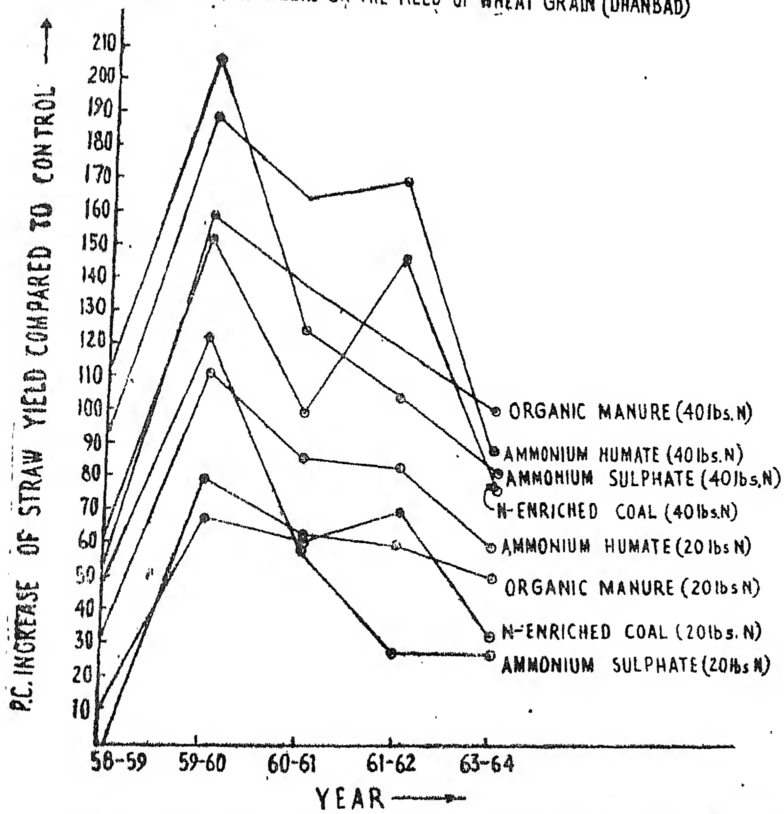

FIG. 4 - EFFECT OF FERTILIZERS ON THE YIELD OF WHEAT STRAW (DHANBAD)

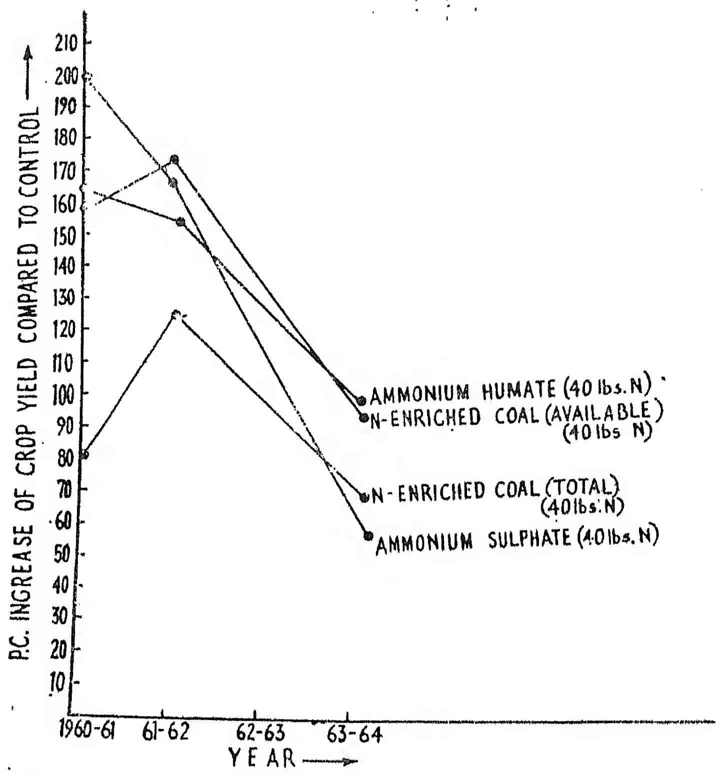

FIG.5- EFFECT OF FERTILIZERS ON THE YIELD OF PADDY GRAIN (HAZARIBAGH)

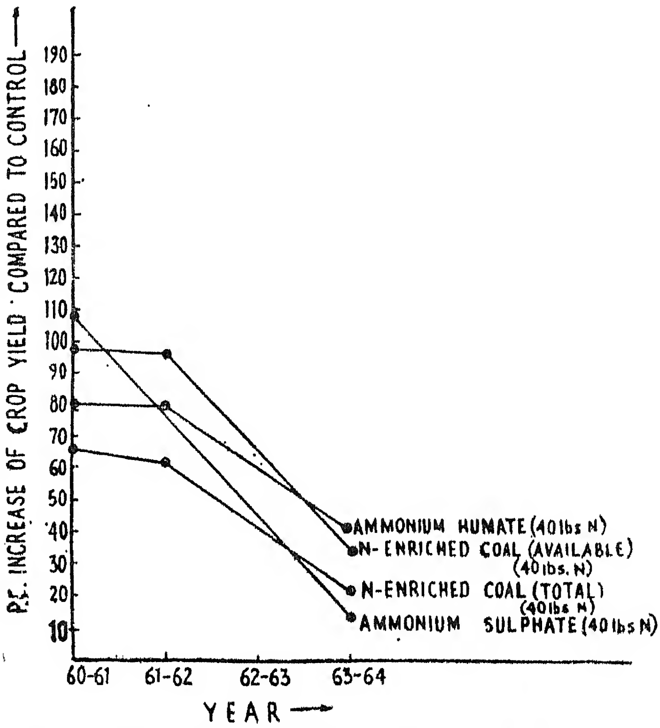

FIG.6- EFFECT OF FERTILIZERS ON THE YIELD OF WHEAT GRAINS (HAZARIBAGH)

From an inspection of the curves in Figure 1 it is evident that though ammonium sulphate gives the maximum yield for the first two years of application, from the third year onwards coal-fertilizers as well as organic manure establish their superiority over ammonium sulphate. The superiority of organic fertilizers over ammonium sulphate on contained application may be explained in terms of the residual effect. It seems very likely that organic manures in general retain nitrogen in soils for long and the so-called unavailable nitrogen in nitrogen-enriched coal is rendered available under field conditions. The same conclusions may be derived from an examination of Fig. 2-6. In case of wheat (Fig. 3), an erratic variation is observed in the percentage increase in the yield of crops from year to year. But it is significant that the same order (as in Fig. 1) is maintained as regards relative efficiency of different fertilizers. Similar trends are discernable from Figs. 5 and 6. From an overall inspection of the experimental results it appears that in point of efficiency coal-fertilizers are superior to ammonium sulphate from a long-term view point.

TABLE 3

Effect of Different Fertilizers on the Yield of Paddy Grain, (Dhanbad)

Treatment	Yield in mds/acre (1 md. = 82 lbs. approx.)			
	1958-59	1959-60	1960 61	1963-64*
Ammonium suphate at 60 lbs. N/acre	44·89	45·62	41·38	25·90
Ammonium humate at 60 lbs. N/acre	38·84	45·30	46·00	39·51
Organic manure at 60 lbs. N/acre	35·29	37·09	38·98	40·28
N-enriched coal at 60 lbs. N/acre	31·04	35·61	41·19	35·92
Ammonium sulphate at 30 lbs. N/acre	33·34	30·95	27·40	16·40
Ammonium humate at 30 lbs. N/acre	28·90	31·24	33·50	20·78
Organic manure at 30 lbs. N/acre	27·08	28·11	26·97	23·86
N-enriched coal at 30 lbs. N/acre	25·04	26·34	37·70	18·21
Control (No fertilizer)	21·04	21·89	19·16	11·80
C. D. at 5%	2·48	3·05	4·60	0·577

*Due to draught conditions, the overall yield of crops was poor.

TABLE 4

Effect of Different Fertilizers on the Yield of Paddy Straw, (Dhanbad).

Treatment	1958-59	1959-60	1960-61	1963-64*
Ammonium sulphate at 60 lbs. N/acre	315·54	332·31	309·82	79·28
Ammonium humate at 60 lbs. N/acre	249·90	324·00	346·00	91·09
Organic manure at 60 lbs. N/acre	239·72	285·47	300·01	93·14
N-enriched coal at 60 lbs. N/acre	210·55	278·15	313·70	85·44
Ammonium sulphate at 30 lbs. N/acre	222·60	234·74	214·68	59·53
Ammonium humate at 30 lbs. N/acre	292·66	233·79	243·71	58·24
Organic manure at 30 lbs. N/acre	211·11	220·84	211·84	63·12
N-enriched coal at 30 lbs. N/acre	179·02	218·36	219·31	62·09
Control (No fertilizers)	147·86	170·33	156·37	50·80
C. D. at 5%	12·22	28·14	44·65	1·834

*Straw was sun-dried before weighing.

TABLE 5

Effect of Different Fertilizers on the Yield of Wheat Grain, (Dhanbad).

Yield in mds/acre.

Treatment	1958-59	1959-60	1960-61	1961-62	1963-64
Ammonium sulphate at 40 lbs. N/acre	8·67	7·91	7·71	7·64	9·48
Ammonium humate at 40 lbs. N/acre	7·43	7·60	7·82	7·98	10·31
Organic manure at 40 lbs. N/acre	6·68	6·33	7·69	7·67	10·91
N-enriched coal at 40 lbs. N/acre	6·26	5·89	6·56	7·41	9·90
Ammonium sulphate at 20 lbs. N/acre	5·77	5·42	5·30	4·91	6·99
Ammonium humate at 20 lbs. N/acre	4·80	5·09	5·21	5·45	8·02
Organic manure at 20 lbs. N/acre	4·48	4·56	4·62	5·02	8·88
N-enriched coal at 20 lbs. N/acre	4·44	3·83	4·46	5·21	6·53
Control (No fertilizer)	3·38	2·85	2·89	2·79	5·31
C. D. at 5% level	0·55	0·11	0·23	0·29	0·07

TABLE 6

Effect of Different Fertilizers on the Yield of Wheat Straw, (Dhanbad).

Yield in mds./acre

Treatment	1958-59	1959-60	1960-61	1961-62	1963-64
Ammonium sulphate at 40 lbs. N/acre	16·76	21·32	17·97	16·88	20·00
Ammonium humate at 40 lbs. N/acre	16·16	20·00	21·22	22·22	20·38
Organic manure at 40 lbs. N/acre	12·05	17·97	19·07	18·11	21·09
N-enriched coal at 40 lbs. N/acre	12·76	17·09	16·02	20·27	19·57
Ammonium humate at 20 lbs. N/acre	10·37	14·62	14·88	15·09	17·43
Organic manure at 20 lbs. N/acre	7·35	12·43	13·02	13·15	16·40
N-enriched coal at 20 lbs. N/acre	8·65	11·61	12·87	14·03	14·40
Control (No fertilizer)	7·86	6·94	8·02	8·23	10·93
C. D. at 5% level	1·07	2·34	1·99	1·73	0·337

TABLE 7

Effect of Different Fertilizers on the Yield of Paddy Grain (Hazaribagh).

Yield in mds./acre.

Treatment	1960-61	1961-62	1963-64
Ammonium sulphate at 40 lbs. N/acre	51·60	50·86	26·66
Ammonium humate at 40 lbs. N/acre	45·47	48·72	33·54
N-enriched coal (available) at 40 lbs. N/acre	44·35	52·43	33·10
N-enriched coal (total) at 40 lbs. N/a cre	32·00	42·95	28·58
Control (No fertilizer)	17·24	19·19	17·34
C. D. at 5%	2·07	1·98	2·78

TABLE 8

Effect of Different Fertilizers on the Yield of Wheat Grain, (Hazaribagh).

Treatment	1960-61	1961-62	1963-64
Ammonium sulphate at 40 lbs. N/acre	20·82	19·81	15·50
Ammonium humate at 40 lbs. N/acre	18·07	20·09	19·16
N-enriched coal (available) at 40 lbs. N/acre	19·81	22·02	13·38
N-enriched coal (total) at 40 lbs. N/acre	16·62	18·11	16·55
Control (No fertilizer)	10·03	11·21	12·67
C. D. at 5% level	1·73	1·21	2·04

Summary

Field experiments were carried out with a new class of fertilizers prepared from coal by reacting coal with air and ammonia at a moderate temperature. A comparative study of the performance of coal-fertilizers vis-a-vis ammonium sulphate, under field conditions indicate that coal-fertilizers are in the long-run more efficient than ammonium sulphate. The superiority of coal-fertilizers are ascribed to their residual effect as well as the humus content.

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The relation between Soil Carbon and Soil Fertility in Indian Soils

By

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The soil carbon content is important in determining the responsiveness of the soil to the application of fertilizers and is also directly related to soil nitrogen. Although extensive studies have been made in India on the relationship between soil carbon and soil nitrogen little information exists between this and available nitrogen.

A near linear relationship exists between the carbon content of the soil and the alkaline permanganate mineralisable nitrogen in each of the eleven out of fourteen blocks distributed all over India indicating that this available nitrogen comes from two equally important sources, the organic and the inorganic. Available nitrogen was 1·57 to 1·40 per cent of the soil carbon in the Alluvial soils of the semi-arid region (Delhi and Nilokheri blocks); 1 20 per cent in the old alluvium of Assam and red soils of Bihar (Udalgiri and Dumka); 0·96 to 0·93 per cent in the coastal and deltaic alluvium (Samalkot and Junagarh) and (·78 to 0·61% percent in the per-humid alluvial and lateritic soils (Agartala, Alwaye and Mangalore) as well as the semi-arid to arid yellow-red soils of Ajmer.

The average nitrogen independent of carbon was also found to be nearly constant in each of the above four groups being 112 to 106 Kg/ha in the first, 105 to 91 in the second, 84 to 79 in the third, and again 118 to 184 in the fourth group. The significance of these findings to soil testing and the irregularity of these relationships in the remaining three blocks at Simla (Hill soils) Summerpur (arid) and Raipur (Mata and Matasi soils) have to be taken into account in making fertiliser recommendations based on organic carbon.

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Problems of Soil Fertility and its Improvement

By

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India is passing through a crisis of acute food shortage. This problem is not confined to India alone, in fact most of the under developed countries are faced with similar situation. In the last 25 years very significant changes have taken place in world wide man-land-food relationship. Before the last war the less developed nations were exporting over 10 million tons of grain per year to the developed countries. After the war this flow has reversed. Now a situation has arisen that our country has to import a very high percent of the total food required in the country from foreign countries particularly from U.S.A. The continuous droughts in the last two years have worsened the situation. According to most conservative estimates the population of the world will double itself by the turn of the century. In Asia the increase will be more than double. The population explosion is not confind to Asian and African Nations even in U.S.A. and Europe, there will be considerable increase in population. Thus even those countries which have surplus food today may find hard even to meet their own domestic requirement.

Alongwith this question there is another problem of the scarcity of cultivable land. Already in India 43 per cent of the total land is being cultivated. This is the highest percentage in the world. The scope for bringing more areas under the plough is very small. Moreover, the cost of conservation and bringing new areas in good shape for cultivation makes the project very costly and widens the cost benefit ratio. Therefore, the only practical solution of the problem is to increase the yield per acre. In fact the yield per acre is not an adequate measure of the productivity of the soil. We have to think more in terms of yield per unit area per unit time and aim at increasing production per hectare per day. Experiments have shown that it is possible to produce as much as 45 50 Kg. grain/Ha per day by making use of new high yielding strains intensive cropping and heavy use of fertilisers. The key to increased production is the improvement in soil fertility and without which the potential of the high yielding seed also cannot be realised.

The soil fertility level of the Indian soils is very low because of the centuries exploitation through cropping and losses of nutrients through leaching and erosion. Nitrogen is universally deficient and without the application of nitrogen through fertilisers or manures, it is not possible to obtain high yields. In fact it would not be far from the truth to say that the food shortage in India to a great degree is linked with the N shortage in the soil. The measures such as green manuring, use of blue green algae, Azotobacter or other bacterial cultures are not adequate to supply the high requirements of nitrogen for obtaining high yields of crops. In

fact, these measures are suited only for a low level of production. It is pointless to argue whether it is cheaper to produce nitrogen in the factory or in the soil. The best strategy will be to encourage all those processes which helps in the recuperation of soil nitrogen without interfering with the intensive cropping and add adequate amount of nitrogen from fertilisers and manures, so as to meet the high requirement of the crops. To illustrate the point in the following table is given the amount of nutrients removed by two crops of paddy (Taichung Native I) in succession (Richaria Patnaik and Choudhry 1965).

	Nutrient removed Kg/Ha		
Nutrient	Grain	Straw	Total
N	154	90	244
P	34	19	53
K	45	406	451
Ca	14	50	64
Mg	17	40	57
Fe	3·5	9·5	13·0
Mn	1·4	13·0	14·4

From this it would be appreciated that there is tremendous strain on nutrient reserves of the soil and without an application of N and other nutrients from external sources, it is difficult to meet this demand of the crop from the natural reserves. A paddy wheat farmer who is producing 60 quintals of wheat and the same amount of paddy is robbing the soil of 275, 125, 336 kg. of N, P_2O_5 and K_2O annually.

The soil testing summaries show that 19 to 84 per cent soils are deficient in phosphorus. Besides the inherent deficiency, there is also the problem of phosphate fixation. It is particularly very serious in laterite and red soils. The choice of the phosphatic fertiliser and soil amendments which can reduce fixation depends on a number of factors in correcting soil reaction and thereby increasing the availability of natural as well as applied phosphorus. The use of lime, basic slag and other liming materials like Pressmud has been well demonstrated in field experiments in Punjab, Bihar, Madhya Pradesh, Mysore and Kerala (Kanwar 1964, Mandel 1967, Motiramani 1967, Mani (1967). In view of the shortage of sulphur for the manufacture of superphosphate, great importance is being attached to the direct use of rock phosphate, basic slag and similar less water soluble phosphates. Efforts have to be made to mobilise the native reserves of phosphates in the soil and increase the efficiency of phosphatic fertilisers which are already in scarce supply. Greater use has to be made of the more citrate soluble phosphates than of water soluble phosphate. The choice of the soil, crop and agronomic practices is most important in this regard.

The Agronomic experiments conducted under the coordinated scheme by Indian Council of Agricultural Research have shown the higher responses to NPK than NP, NK or N alone all over India in wheat, rice, maize and many other crops. The soil test summaries show that 11 to 77 per cent of soils are deficient 19-58 per cent have medium supplies of available K in the soil. The importance of potash will increase with the emphasis on high yielding varieties and intensive

cropping. The total amount of potash in soils is fairly satisfactory but its availability is low. The fixation of potash is also a problem. Kanwar and Grewal (1966), observed that the recovery of potassium from the fertiliser source by three crops ranged from 53 to 62·2 per cent in the presence of balanced dose of NP. Considerable amount of fertiliser K was transferred to the fixed form in the soil and the first paddy crop removed - 0·7 to + 43·7 per cent and subsequent wheat crop derived 24·8 to 53·1 per cent of their K from the fixed form. It was concluded that the application of higher doses of K fertilisers decreased the release of fixed soil K to paddy and wheat crops. Grewal and Kanwar (1966) concluded that on an average Punjab soils contained about 6 per cent of the total K in the soil in a fixed form. In most of the alluvial soils of northern India, which contain illite type of minerals, the potassium fixation is quite a serious problem. Even the ammonia fixation in these soils is very high hence the efficiency of nitrogenous fertitisers is very low. The nitrification and availability of native and fertiliser fixed ammonia is quite low. The fertiliser fixed ammonia is comparatively more available. Thus it will be appreciated that in the alluvial soils of India besides the total nitrogen and ammonia being low, even the applied ammonical fertilisers loss quite a high amount due to fixation of ammonia.

No doubt the importance of N, P and K in increasing crop production has been realised in the country, but the secondary nutrients particularly Mg and S have not received any attention.

Kanwar and Randhawa (1967) have focussed attention on the wide spread deficiency of sulphur in Indian soils. At present the deficiency of sulphur is quite serious in groundnut, berseem and other legum ecrops but it is likely to get aggrevated because of intensive cropping and use of high analysis fertilisers deficient in sulphur. Use of compounds such as gypsum for correcting the deficiency of sulphur has been found very efficacious in case of ground soil by Kanwar (1963), Dalal, Kanwar and Saini (1963) and Chopra and Kanwar (1966) and Kanwar and Randhawa (1967). It is also observed that there is a definite relationship between the N : P (org.) and S (org.) in a soil.

The deficiencies of micronutrients are very wide-spread in India. The most common deficiency is of zinc though responses to Fe, Mn and Cu, Mo and B are also recorded in many soils and crops. Kanwar and Randhawa (1967) have reviewed the work done on micronutrients in India. The authors have emphasised the indequacy of research on micronutrients in soils and crops in India. They have aalso observed that as a result of intensive cropping and heavy fertilisation the micronutrient deficiency will become more serious. Thus a sound knowledge of the techniques of increasing the availability of micronutrients in soil is necessary.

To sum up it may be concluded that the fight for increasing the food production in India has to be fought on the soil front and the soil fertility holds the key to this important problem. In future greater importance may have to be attached to the supply of micronutrients and sulphur, alongwith NPK for increasing yields. The understanding of the problems of the availability of these nutrients in the different soils in India, will be essential for making the rational use of our limited resources of fertilisers.

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Fertility of the Himalayan Soils (I)

By

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Introduction

Himalayas, very recently, has assumed great importance both from the political and economic objectives. The scientific knowledge, however, on the several attributes of this terrain almost completely lacks and only in the present times scientists from different disciplines have diverted their attention to study this little investigated Himalayan belt. A famous Indian historian K. M. Pannikar recently recorded, 'the Himalayas will undoubtedly become a major object of political and economic interest. The study of Hamalayan geography, geology, flora, fauna, its climatological phenomenon and a hundred other matters connected with its life has now become most urgent for all students interested in the welfare of India'.

Soil forms a very important natural resource for the development and progress of an area. Though this resource can be studied and utilized in different forms by different workers, the basic necessity—the food—depends on the potential fertility of the soils. Both physical and chemical properties in conjunction with the physiography and the climate combine to determine the best means of utilization of the soil resource in a particular region.

The present paper deals with the fertility aspect of the soils of the Simla forests in Himachal Pradesh.

Experimental

Four representative soil profiles from the Mashobra-Guma area in Himachal Pradesh, carrying natural flora of evergreen conifers comprising Deodar, Kail and Chir pines and situated along different elevations ranging between 3,850 feet and 7,400 feet, underlaid by different parent materials, are reported in this paper. A general description of the soils is given in Table 1.

The total nutrients as reported here, were determined in HCl extract, A.E.A. Provisional method as given by Piper (1950). Available P_2O_5 and K_2O were determined by Dyer's method as 1% citric acid soluble fractions. Organic carbon was estimated by Walkley and Black wet digestion method, total nitrogen by Kjeldahl modified A. O. A. C. procedure (1955); conductivity and pH in 1 : 2 and 1 : 2·5 soil : water suspensions respectively, Piper (1950); mechanical analysis by International pipette method after dispersion with sodium-hexa-metaphosphate as described by Kilmer and Alexander (1949).

Results and Discussion

Analytical data as presented in Table 1 indicate the texture of the soils to vary between sandy loam to silt loam with slightly heavier sub-soils.

Moisture content of the air dry samples in profile I and IV appears to be closely related with the loss on ignition (Tamhane and Lote, 1954 and Coutts, 1929). However, in the case of profile II and III it varies with both loss on ignition and the clay content. Such a correlation between hygroscopicty and the

clay content has been reported by Keen *et al* (1928). Further the loss on ignition shows an apparent dependance on both organic matter and the clay content in profiles I and III. Similar observations are also made when loss on ignition at similar levels of organic matter and clay content are compared in case of profiles I and IV. In profile II clay content seems to have a greater affect on the loss on ignition than what is evident in other profiles. Tamhane and Kaul (1956) in their investigations on Kashmir soils concluded that the loss on ignition varies with a corresponding variation in the organic matter content. After statistically analysing the data, a very highly significant correlation (r = + 0·76) was observed between loss on ignition and orgainc matter, while the correlation between the loss on ignition and the clay content was also significantly high (r = + 0·54).

TABLE I

Physical characteristics of the soils

Depth in inches	Moisture %	Loss on ignition %	Texture	Clay %	Water holding capacity %	pH	Conductivity m. mhos/cm
I 0–3	4·02	10·40	Loam	23·51	59·24	6·60	0·09
3–9	3·52	7·19	Silt loam	19·85	54·92	6·30	0·11
9–10	3·24	6·55	Silt loam	26·65	49·20	6·45	0·36
19–29	3·14	6·55	Clay loam	30·74	43·43	6·20	0·26
29–39	2·96	6·49	Clay loam	32·85	42 37	6·15	0·29
39–49	2·94	6·06	Loam	29·37	43·98	6·10	0·21
49-59	2·19	5·87	Sandy clay loam	29·95	45·97	5·30	0·18
II 0–3	3·63	8·46	Silt loam	24·81	78·72	6·35	0·39
3–12	3·76	7·67	Silty clay loam	34·15	54·85	6·35	0·18
12-24	3·86	6·87	Silty clay loam	35·56	43·96	6·30	0·23
24–30	4·17	10·52	Silty clay loam	38·96	63·74	6·90	0·22
30–48	4·15	7·76	Silty clay loam	37·76	67·17	7·60	0·34
III 0–5	2·30	8·54	Sandy clay loam	21·14	48·14	6·10	0·25
5-14	1·98	7·19	Sandy loam	19·24	38·47	6·30	0·24
14–24	1·29	5·41	Sandy loam	15·17	30·09	6·50	0·17
24–34	0·83	5·45	Sandy loam	11·98	27·14	6·70	0·14
34–44	0·55	5·40	Sandy loam	11·94	26·72	6·85	0·19
44-60	0·55	5·33	Sandy loam	12·05	28·11	7·10	0·27
IV 0–2	1·83	10·74	Loam	23·11	56·21	7·90	0·24
2–8	1·07	8·99	Loam	24·31	49·45	8·05	0·34
8–18	1·72	10·13	Loam	24·85	43·24	8·10	0·34
18–28	1·78	10·87	Loam	25·20	44·48	8·05	0·32
28-38	0·50	7·94	Loam	28·06	43·40	8·20	0·27
38-48	2·40	7·65	Loam	24·86	43·02	8·15	0·24
48-58	2·30	5·67	Loam	26·59	43·49	8·05	0·31

Data reported on oven dry basis.

TABLE 2

Total and available nutrients

Depth in inches	Organic carbon	Total N	C : N ratio	Phosphoric acid HCl solu.	Phosphoric acid Citric acid soluble %	Potash HCl solu.	Potash Citric acid soluble 1%	CaO HCl soluble
I 0–3	2·31	0·127	18·18	0·12	0·0065	0·40	0·014	0·62
3–9	0·90	0·084	10·71	0·12	0·0063	0·45	0·015	0·42
9–19	0·61	0·059	10·33	0·10	0·0053	0·62	0·020	0·43
19–29	0·32	0·036	8·88	0·10	0·0055	0·72	0·024	0·42
29–39	0·21	0·030	7·00	0·07	0·0040	0·63	0·021	0·40
39–49	0·13	0·019	6·84	0·10	0·0058	0·56	0·020	0·31
49–59	0·08	0·012	6·91	0·13	0·0067	0·50	0·014	0·25
II 0–3	4·58	0·124	36·90	0·16	0·0090	0·51	0·019	1·62
3–12	1·34	0·113	11·85	0·10	0·0061	0·57	0·024	1·18
12–24	0·32	0·041	7·80	0·16	0·0083	0·43	0·021	0·84
24–30	0·33	0·041	8·04	0·13	0·0071	0·47	0·022	1·01
30–48	0·52	0·062	8·06	0·15	0·0076	0·54	0·024	3·19
III 0–5	1·70	0·115	14·78	0·12	0·0071	0·78	0·035	0·56
5–14	0·68	0·060	11·33	0·12	0·0072	0·58	0·030	0·34
14–24	0·37	0·039	9·48	0·08	0·0051	0·56	0·030	0·32
24–34	0·25	0·027	9·22	0·08	0·0053	0·71	0·034	0·30
34–44	0·19	0·023	8·17	0·13	0·0073	0·78	0·038	0·60
44–60	0·18	0·024	7·54	0·09	0·0058	0·72	0·039	0·66
IV 0–2	2·13	0·167	12·75	0·20	0·0100	0·91	0·038	1·96
2–8	1·24	0·109	11·37	0·16	0·0083	0·91	0·043	6·58
8–18	0·85	0·083	10·24	0·19	0·0061	0·91	0·043	8·32
18–28	0·76	0·078	9·61	0·19	0·0063	1·06	0·051	7·45
28–38	0·51	0·066	7·72	0·17	0·0049	1·12	0·052	11·73
38–48	0·50	0·072	6·94	0·20	0·0060	0·81	0·041	6·13
48–58	0·40	0·058	6·89	0·16	0·0058	0·65	0·037	4·48

Data reported on oven dry basis.

Water holding capactiy of the soils ranges from 42·37% to 78·72%. Through comparing the values at similar levels of clay and organic matter, the silt fraction appears to contribute to the water holding capacity of the soils (Batra *et al*, 1946 and Tamhane and Kaul, 1956).

All the four porfiles have a slightly acidic to mildly alkaline reation (pH 6·1 to 8·2). The general trend towards acidity in profiles I, II, and III may be attributed to the free drainage conditions under the prevailing humid climate and the lighter texture of soils. The alkaline reaction of profile IV (pH 7·9 to 8·2), seems to be due to the very high Ca saturation as is evident from the high CaO content throughout the profile depth. The low conductivity values of 0·09 m.mhos/cm. to 0·39 m.mhos/cm. also reflect upon the freely drained nature of the soils.

Organic carbon ranges from 0·08 to 4·58%, while the nitrogen varies between 0.012 and 0·167%. The C: N ratios of the surface layers range from 12·75 at 3,850 feet to 36·9 at 6,600 feet elevation. In the present investigation an increase in organic matter with increasing altitude is noticed in profiles II, III and IV (Siveres and Holtz, 1923 ; Raychaudhri and Sen, 1957 ; Jenny and Raychaudhri, 1960). The C : N ratios also become wider with rise in elevation. The wider C : N ratios along higher elevations are attributed to the lower microbial activity under decreasing temperatures. Martin (1943) observed C : N ratios from 6·3 to as wide as 64·8 in the Mt. Graham soils. Jenny (1948) reported C : N ratios of 33·7 at 5,350 feet elevation in the Humic Yellow Brown soils of Columbia. The lower C : N ratio and the organic matter content in the surface layer of profile I at 7,400 feet elevation is attributed to its situation along steeper slope which would have eroded down or deposited here finer materials from the slopes above. This is supported by the slight enrichment of the surface layer of profile I with clay content. A thin stand of Kail as compared to the dense Deodar forest over profile II, could be another reason for the comparative lower content of the organic matter in profile I.

Nitrogen, in general, increases with an increase in altitude (Jenny, 1928–30 ; Hockensmith and Tucker, 1933). The relatively higher nitrogen content in profile IV, however, may by attributed to the grassy and bushy vegetation and the relative rapid mineralization of the organic matter as affected through greater microbial activity under milder temperatures.

Though the HCl soluble constituents do not give a fair idea of the availability of the nutrients to plants, it does give a measure of the potential nutrient content which will be made available to plants over a long period.

Phosphoric acid (Table 2) shows an irregular distribution within the profiles. In profiles I and II which have originated from the similar parent materials, it is observed that profile I under Kail (*Pinus excelsa*) forest and situated at a higher elevation (by 1,100 feet above profile II) is poorer in all the nutrients as compared to profile II under the Deodar stand. The Deodar needles contain twice the lime content as compared to those of Kail and thrice as that in Chir pine needles. This seems to have conserved the phosphorus and basic constituents in profile II. The sandy nature of the parent material and the Chir cover profile III have resulted in conditions similar to those in profile I, though the minor variations can be attributed to the differences in the parent rocks underlying these profiles. The relative higher phosphorus content in profile IV appears to be due to the precipitation of phosphorus as calcium phosphates at the prevailing soil reaction and high CaO content.

An illuviation of potash into the lower horizons within profiles as well as its accumulation down slope the ridge, is observed from Table 2. Due to free percolation and surface drainage it is obvious that the monovalent basic constituents heave moved down both vertically and laterally along the slope under the prevailing conditions of high precipitation and well drained conditions. As the potassium ion does not enter into any permanent organic combination in plant tissues, it can be readily leached from the non-living plant tissues (Lawton and Cook, 1954). This supports the assumption made above that potassium leaches down the slope due to surface drainage from the leaf debris which accumulates in large proportions under forest covers.

The data for the first 30 inches of soil depth were considered to characterise the potential nutrient status of the soils. The assessment based on the conventional

limits referred to, by Sharma *et al* (1956) during their investigations on the Simla soils, is given below :

Nutrient	Percent range	Status Classed as
Phosphorus	0·10 to 0·20	good
Potash	0·40 to 1·0	excellent
Total N	0·167 to 0·036	good
Organic carbon	4·58 to 0·32	adequate to very good

Available P_2O_5 ranges between 0·0040 to 0·01 percent and appears to be a function of the total phosphate content ($r = + 5605$) and soil reaction ($r = + 6701$). The relatively higher proportion of soluble phosphorus in profile III may be due to the better drained conditions than in other profiles. Rangaswamy *et al* (1966) and Gletworth (1947) have reported that citric acid soluble phosphates in the freely drained soils are usually high.

The citric acid soluble potassium ranges between 0·014 and 0·052 percent. This also is related positively with the HCl soluble potash and also shows greater availability in the soil pH range of neutral to alkaline.

Both available phosphorus and potash appear to be inadequate to only fair and it indicates that the fertilizer applications in the areas which are put to use for orchards or cultivation, will prove advantageous.

Summary

A study was made to evaluate the fertility of the forest soils of Mashobra (Himachal Pradesh). Four representative soil profiles from the area were studied which are reported in this communication. The moisture content of the sandy loam to silt loam soils showed close relationship with the clay fraction and the loss on ignition. Similary the loss on ignition was observed to be a function of both organic matter and the clay content. The soils are freely drained and are slightly acidic to mildly alkaline in reaction (pH 6·1 to 8·2) with low conductivity values. Both organic matter and nitrogen increased with increasing elevation of the profile sites. The C : N ratios, however, became wider at higher elevations (12·75 to 36·9), reflecting upon the reduced microbial activity due to lower temperatures on higher elevations. The phosphorus, potash and lime status of the soils appeared to be a function of the vegetation cover, prevailing humid climate and well drained conditions in the profiles.

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Fertility of the Himalayan Soils (II)

By

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Introduction

Fruits cultivation occupies an important position in the hilly areas of the Himalayan belt. In areas like that of Kotgarh in Himachal and Ramgarh and Ranikhet in Central Himalayas, apples and other temperate fruits cultivation has developed rapidly and made the local economy affluent. However, the expansion of horticultural programme in these areas, largely depends on the physiography, climate and soils. Elevation has a great bearing in determining the suitablity of the area for apples and for the cultivation of other temperate fruits. The scope of the study a part of which is reported in this paper is limited to the investigations on soils of some western and central Himalayan areas. Trace-elements affect both crop and animal production as both temperate fruits and the sheep and goat raising has certain special demands for the particular micro-nutrients.

This communication deals with the distribution of Manganese and Copper in the podsolic soils of areas around Simla and Almora. As few studies have been made on the trace-element status of the soils of the Himalayan tract, this communication, it is believed, will make an important contribution to that end.

Material and Methods

The profiles reported here, were collected from the Simla forests of Mashobra in Mahasu district of Himachal Pradesh and the Khatiari and Gananath areas of Almora district in Uttar Pradesh. The areas are covered with conifers and are situated at elevations ranging between 5,500 and 7,500 feet.

The soils belong to the great soil groups of Grey Brown Podsolic soils and Brown Forest soils. In profiles II and III a slight lateritic tendency (communicated elsewhere) is noticed. The soils are sandy loam to clay loam in texture and the sub-soil is usually enriched with the finer fractions.

Total Mn was determined in HCl extreat (A. E. A. Provisional method) as described by Piper (1950). Mn concentration was recorded colorimetrically following the para-periodate method. Exchangeable Mn was determined by extracting with normal ammonium acetate (pH 7·0) and water soluble as described by Jackson (1958). Total Cu was determined by fusion method reading the concentration on Klett's colorimeter following carbamate method given by Jackson (1958). Perchloric acid extractable Cu was estimated after Jackson (1958).

Results and Discussion

Analytical data on different soil characteristics and the different forms of Mn and Cu are given in a tabular form. A perusal of the data indicates highest content of HCl soluble and exchangeable in the surface horizons, decreasing

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Soil characteristics and forms and distribution of Manganese and Copper in podsolic soil profiles

Profile	Depth in inches	Texture	Clay	Loss on ignition	Organic carbon	pH	CaO	Manganese (ppm) Water soluble	Manganese (ppm) Exchange-able	Manganese (ppm) Total	Copper (ppm) $HClO_4$ extract-able	Copper (ppm) Total
I	0–3	Loam	23·51	10·40	2·31	6·60	0·62	4·5	134·0	365·0	3·0	19·2
	3–9	Silt loam	19·85	7·19	0·90	6·30	0·42	6·5	62·0	310·0	2·7	28·0
	9–19	Silt loam	26·65	6·55	0·61	6·45	0·43	5·0	58·0	305·0	3·6	20·8
	19–29	Clay loam	30·74	6·55	0·32	6·20	0·42	1·5	33·0	301·0	3·6	20·2
	29–39	Clay loam	32·85	6·49	0·21	6·15	0·40	2·75	15·5	295·0	5·0	20·4
	39–49	Loam	29·37	6·06	0·13	6·10	0·31	4·5	11·0	285·0	3·0	25·0
	49–59	Sandy clay loam	29·95	5·87	0·08	5·30	0·25	12·5	20·0	275·0	0·6	25·6
II	0–3	Silt loam	24·81	8·46	4·58	6·35	1·62	1·6	124·0	310·0	1·0	22·0
	3–12	Silty clay loam	34·15	7·67	1·34	6·35	1·18	2·0	98·0	265·0	2·0	25·2
	12–24	Silty clay loam	35·56	6·87	0·32	6·30	0·84	0·5	29·0	265·0	4·0	23·8
	24–30	Silty clay loam	38·96	10·52	0·33	6·90	1·01	1·7	108·0	298·0	3·1	22·0
	30–48	Silty clay loam	37·76	7·76	0·50	7·60	3·19	3·0	62·0	287·0	2·3	18·8
III	0–5	Sandy clay loam	21·04	8·54	1·70	6·10	0·56	2·0	128·0	455·0	4·3	26·8
	5–14	Sandy loam	19·24	7·19	0·68	6·30	0·34	3·0	125·0	455·0	4·6	29·2
	14–24	Sandy loam	15·17	5·41	0·37	6·50	0·32	2·4	82·0	320·0	2·6	27·2
	24–34	Sandy loam	11·98	5·45	0·25	6·70	0·30	2·0	79·0	310·0	3·2	27·8
	34–44	Sandy loam	11·94	5·40	0·19	6·85	0·60	2·5	81·0	220·0	3·1	28·2
	44–60	Sandy loam	12·05	5·33	0·18	7·10	0·66	3·0	79·0	310·0	2·5	29·2
IV	0–4	Sandy loam	10·0	6·70	1·19	6·30	0·57	2·0	125·0	355·0	2·9	15·5
	4–13	Sandy loam	12·1	4·56	0·58	5·75	0·45	2·1	117·0	340·0	4·5	15·7
	13–22	Sandy loam	16·2	4·47	0·22	6·15	0·49	3·0	76·0	337·0	4·7	16·5
	22–37	Sandy loam	18·1	4·36	0·25	6·70	0·41	2·8	70·0	320·0	4·3	17·3
	37–48	Sandy loam	13·2	4·32	0·17	6·80	0·45	2·4	49·0	317·0	3·1	14·0
V	0–3	Sandy loam	10·87	6·95	1·34	5·50	0·81	2·7	117·0	307·0	3·8	19·3
	3–8	Sandy loam	12·95	5·78	0·62	5·85	0·76	2·8	108·0	280·0	3·3	16·7
	8–18	Sandy loam	14·76	4·47	0·29	6·80	0·93	3·0	81·0	251·0	3·2	16·9
	18–30	Sandy loam	15·87	4·48	0·16	6·70	0·80	2·9	74·0	248·0	3·5	17·3
	30–48	Sandy loam	14·88	4·27	0·13	6·90	0·85	2·5	64·0	240·0	3·4	16·8

Data reported percent oven dry basis.

gradually with depth in all the profiles. Yadav and Kalra (1964), Robinson (1929), Leeper (1947), Biswas (1953) and Lag and Dev (1964) have also reported similar findings elsewhere. This has been attributed by several workers to migration of the element through vegetation, and this may be true in the case of soils under the present study also, which contain appreciable amounts of organic matter in the surface layers. Statistically a significant positive correation between the HCl soluble Mn and the organic carbon content (r = + 0·8132) has been obtained. Also that organic matter is responsible for the Mn distribution within the profiles is evident from the slight illuviation of humus accompanying increment in exchangeable and HCl soluble Mn in the sub-soil layer of profile II (Lag and Dev, 1964). As regards the clay content, except for porfile III, the HCl soluble Mn did not appear to be associated with this factor. However, though statistically non-significant (r = + 0·4771) total Mn was observed to be higher at higher levels of clay fraction in profile III.

Exchangeable Mn gave a significant correlation with organic carbon (r = + 0·7201) and pH (r = + 0·7315) of the soil samples (Sherman *et al*, 1942 ; Khanna *et al* (1954) ; Duarte *et al*, 1961 ; Yadav and Kalra, 1964). On profile basis no relationship was obtained between pH and exchangeable Mn except ir case of profile I where exchangeable Mn increased with the rise in soil pH. Clay content did not give a significant correlation with exchangeable Mn (r = + 0·3732). Further the higher content of exchangeable Mn in the lower horizons of porfile II may be due to the anaerobic conditions inducing reduction processes and also to the translocation of the element from upper layers with its consequent accumulation in the zone of imperfect drainage (Yadav and Kalra, 1964). Similar observations have also been reported by Robinson (1929), and others. Imperfect drainage conditions were observed in the field in the layer 24-48″ of profile II. The soil profile was found very wet in the subsoil layers.

Water soluble Mn ranges between 0·5 and 12·5 ppm. The water soluble Mn also shows its general accumulation in the lower horizons which is attributed to leaching from the upper layers. No significant correlation was obtatined between water soluble Mn and pH, organic carbon or clay content within the soil profiles. A positive significant correlation between CaO and water soluble Mn was, however, obtained (r = + 0·5610). Thus an increase in the CaO content increased the water soluble Mn. Sherman (1942), and Christenson *et al* (1950) have reported the lime retards the conversion of water soluble Mn into unavailable forms.

Data on Copper show its irregular distribution within the soil profiles. Cu ranges between 14·0 and 29·2 ppm in the soil profiles reported here. Holmes (1943) reported similar obsevations in a large number of United States soils. He reported a range of Cu concentration from 2 to 67 ppm. Ivanov (1950) in a comparative study of various soils noted that Cu ordinarily varies within a range of 10 to 30 ppm and Lundbald, *et al* (1949) observed it to be between 11 and 176 ppm.

In line with the findings of Gandhi and Mehta (1958), no significant relationship has been observed between Cu and any of the soil characteristics *viz.* pH, organic carbon, clay and CaO content. According to Steenbjerg and Boken (1950) total Cu increases with increasing clay content of the soils. He reported low Cu in sandy soils. In the present study, however, total Cu increases with increasing clay content in all the profiles. In profiles III, IV and V which have lower amounts of clay (10·0 to 21·04%), the copper concentration varies from 14·0 to 29·2 ppm. This represents both the least as well as the maximum Cu concentration observed during these studies. The intensity of soil acidity and composition

of the parent material have considerable influence on Cu distribution in soils. Gilbert (1952) reported that under similar conditions of pH, texture and colour and soils belonging to the same great soil group, the soils derived from granite had far less Cu content than that derived from limestone. Since Cu is more soluble under acid conditions, the soils developed on acidic rocks retain less of Cu of the parent rocks. Similar could be case with profiles IV and V in the present study. These have developed over granites and contain a relatively lower Cu concentration than other profiles. Profile III, which has developed over calcareous quartzite has the maximum value of Cu and also has a relatively high Cu concentration throughout the profile depth.

The $HClO_4$ extractable Cu ranges between 0·6 and 5·0 ppm. Though the extractable Cu did not give any significant relationship with pH, organic carbon and lime, yet the clay content of some of the layers in different profiles appears to be related positively with the extractable Cu concentration. Higher clay content in the pH range of 6·1 and 6·3 in the lower layers of the soil profiles show a relatively higher extractable Cu concentration. Similar observations have been reported by Reintz and Shimp (1953). They found more available Cu in the soils having high clay percentage with acid reaction. It may be due to the fact that at lower soil reaction, more soluble Cu is adsorbed over the clay complex and held available for utilization by the plants.

Availability of Mn and Cu to plants :

In the present investigation the water soluble Mn ranges between 0·5 and 12·5 ppm, the exchangeable Mn between 11·0 and 134 ppm and the HCl soluble Mn between 220 and 455 ppm. According to Raychaudhri and Datta Biswas (1964) an active Mn concentration of 15 to 100 ppm is critical for plant growth and above that it is high. As per this standard the soils of the areas under study, appear to be well supplied with both active as well as total Mn for plant growth.

The concentration of $HClO_4$ extractable Cu is less than 7 ppm in all the profiles. According to Lundbald *et al* (1949) the available copper concentration lesser than 7 ppm $HClO_4$ extractable copper indicates the soil deficiency in available copper. Raychaudhri and Datta Biswas also report a total copper concentration of 5 to 8 ppm to be critical for plant growth. These studies show that though the soils of the Himalayan belt around Simla and Almora are high in total copper, yet they are low in the available copper as required for good plant growth. Similar results were reported by Brun (1945) in the Norwegian humus soils.

Summary

Micro-nutrients studies were conducted on the forest soils of the districts of Mahasu (Himachal Pradesh) and Almora (Uttar Pradesh) ; a part of this, comprising studies on Manganese and Copper, is reported in this communication. The soils belong to the great soil groups of Grey Brown Podsolic soils and Brown Forest soils. The HCl soluble Mn was found to be highest in the surface layers which are rich in humus and then decreased with depth (307 to 455 ppm). Exchangeable Mn in general was also higher in the surface horizons (104 to 134 ppm). This trend of distribution of total and exchangeable Mn appeared to be a function of soil reaction and the humus content. Water soluble Mn showed an irregular distribution and did not appear to be associated significantly with any of the soil characteristics except that with the CaO content. Total Cu ranged between 13·5 and 29·2 ppm, showing no relationship with any of the soil characteristics. $HClO_4$ extractable Cu ranging from 0·6 to 5·0 ppm, however, appeared

to be related with the clay distribution within the soil profiles. The status of Mn and Cu in relation to plant growth has also been discussed.

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Blue-green algae and soil fertility

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Soil biological considerations are assuming increasing importance and coherence in soil fertilisation. Generally, the yield capacity of our cultivated soils form a parallel to the soil microbiological activity and consequently the measures which help to increase the biological activity of the cultivated soil will contribute to expand the reservoir of soil nutrients for the crop plants. The past few decades have witnessed remarkable advancements in harnessing some of the useful micro-organisms to build up the soil fertility and to increase the crop yields. An instance of considerable significance is the legume bacterium, *Rhizobium.*

In recent years, blue-green algae, a predominent constituent of the soil biotypes, have been shown to be agriculturally important, particularly in the tropical soils. Their usefulness lies in the capacity of some forms to carry out both photosynthesis and nitrogen fixation. Their contribution towards nitrogen in the soil has been estimated to be 20-40 lbs N/acre, and the increase in the paddy yield as a result of introducing these algae in the soils ranges from 20-50%. Recent investigations indicate that, these algae also contribute to the crop many biologically important substances like vitamins and growth promoting substances, thus forming a good supplement to the inorganic fertilisers.

A large scale application of these algae in our general agricultural practices requires an appreciation of their indigenous distributional pattern in the soils, existence of physiological races and the necessity for preparing the 'seeding material' on a large scale. Equally important is the influence of the microbiocoenotic associations existing in the soil. Recent studies have shown that an associatien of *Azotobacter* and *Rhodopseudomonas* results in a 3-fold increase in the total nitrogen fixed as compared to their individual activities. This syntropic effect also becomes evident in an increase in the yield of paddy and wheat. Studies on such associative effects between nitrogen-fixing blue-green algae and other bacteria will contribute to a better understanding of the relation between soil fertility and soil biology.

The role of microorganisms in relation to high yielding and fertiliser responding varieties also needs experimentation, in view of our intensive agricultural programme.

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The Soil as a Biological System and Its Ecological Significance

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All living organisms interact with their environment. Although the history of man and mankind's immediate future might well be written in terms of soil and water resources it is imperative to realistically appraise all factors of the environment so that we can intelligently plan for present and future needs. Emphasis is commonly placed on soil and water but these and all influencing factors and their interrelationships and interactions must be considered. Only then can possible control or modification be effected to obtain our expanding population's requirements for food, fiber, and shelter. Higher standards of living can arise only insofar as man can use his imagination and skill to adapt materials to applications which would give him an advantage over his environment and aid in improving human resources.

This need calls for action in world agriculture. Where better to begin than with the soil and the factors of environment? The following discussion briefly delineates these factors and their interactions so that all aspects of the various complex phenomena may be brought into focus for future consideration and elucidation.

Many features of the soil and its study resemble those of an organism and they may similarly be categorized. The soil, or pedosphere, is a natural body of definite layers or horizons physically, chemically and biologically derived from the earth's mantle, and having characteristic morphological, constitutional, and physiological features determined by nature of parent material, climate, biosphere and topography. Comprehensively the soil or pedosphere is a mineral-biological complex of organic and inorganic substances composing a dynamic polyphase physical-chemical system in unstable equilibrium with vital phenomena.

The constitution of the pedosphere varies with the proportions and the intensity of action of the different spheres which contribute to its formation. (Fig. 1). No two soils are exactly alike. The great variation of soils is expressed in the activity or dominance of the different spheres. The lithosphere dominates in mineral soils, the biosphere dominates in organic soils, the hydrosphere dominates in ground water soils, and the atmosphere dominates in dry, porous soils.

The fundamental factors of soil composition are usually expressed as *pore space, moisture, organic matter*, and *ash*. These express the proportions in which the atmosphere, the hydrosphere, the biosphere and the lithosphere enter into the make-up of the soil. The composition can be expressed by the formula $L+A+H+B=100$, where the symbols represent the percentage volume (or weight) of the component spheres.

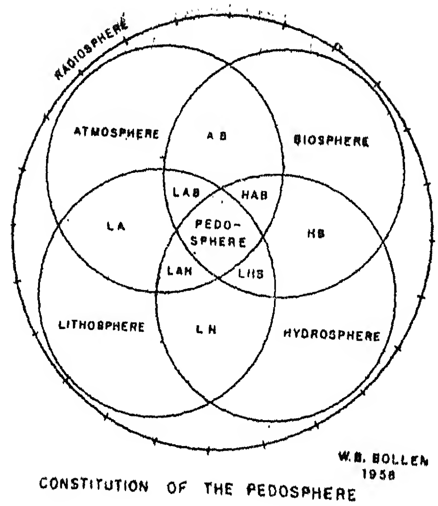


Fig. 1

In addition to being the sum of these components the pedosphere is also the product of their interaction. Interchange of the material between the spheres is continually taking place through hydrolysis, neutralization, oxidation-reduction, synthesis and decomposition, solvation and precipitation, and exchange. This interactivity has been discussed at length by Mattson (2).

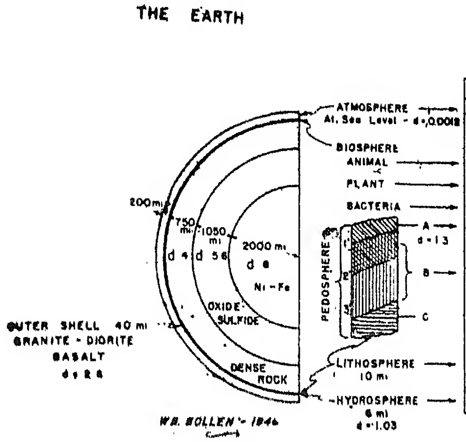
The immediate medium provided by nature for the development of man and other organisms contains many of the essentials in extremely limited concentrations or in forms not generally available. On comparing the composition of the spheres of nature and of the soil (Fig. 2) with the composition of organisms it is evident that organisms are very much richer in carbon and nitrogen. In concentrating these elements in their substance their nutritional systems expend much energy. Eventually their residues enter the soil or the sea, and through progression of the cycles of carbon, nitrogen, and other elements the environment is rendered richer and more productive.

The Biosphere comprises the earth zones inhabited by organisms. It is an important factor in soil development and soil differentiation. Microorganisms, insects, nematodes, worms, higher animals, and plant roots inhabit the soil and impart to it a distinctive physiology, an understanding of which can lead to its management for better crop production.

The Microbosphere extends at least 6000 feet into the lithosphere, but soil microorganisms live chiefly in the *F* horizon of forest and prairie soils and in the *A* horizon of agricultural soils. In arable soils they predominate in the colloidal complex of organic and inorganic materials more or less saturated with water and air and supported by the soil particles, mainly mineral grains, the whole serving as a culture medium.

A pinch of fresh soil contains millions of bacteria and lesser numbers of other microbes. While extremely minute in size, their numbers in an acre of fertile soil comprise an active mass of tremendous surface and considerable weight. This is evident from the values given in Table 1, calculated for one acre of soil to plow depth of 6⅔ inches or 2,000,000 pounds of soil, dry basis (2).

COMPOSITION OF THE SPHERES OF NATURE IN RELATION TO ORGANISMS AND THEIR ENVIRONMENT



ELEMENTAL COMPOSITION. WEIGHT % DRY BASIS

	C.	O	H	N	Si	Al	Fe	C/N
ATMOSPHERE	0.01	23.15		75.51	0.00	0.00	0.00	
ANIMAL	60.95	10.83	7.40	8.93	0.003	0.003	0.03	7/1
PLANT	43.62	44.48	6.24	1.46	1.17	0.11	0.09	30/1
BACTERIA	50.0	30.0	7.0	10.0	0.01	0.00	0.09	5/1
A	1.15	45.00	1.0	0.09	35.65	5.29	2.52	13/1
B	0.46	43.50	0.5	0.05	35.0	8.24	4.01	9/1
LITHOSPHERE	0.09	47.46	0.14	0.00	27.61	8.07	5.06	
HYDROSPHERE	0.00	85.79	10.67	0.00	0.00	0.00	0.00	

Fig. 2

TABLE 1

Living Organisms in a Fertile Soil

	Live weight per acre $6\frac{2}{3}''$	Relative numbers
	Pounds	%
Bacteria	1,000	80–20
Actinomycetes	1,000	20–70
Molds	2,000	1–10
Algae	100	1
Protozoa	200	2
Total	4,300	
Dry-weight =	1,000	
Nematodes	50	
Insects	100	
Worms	1,000	
Plant roots (Dry wt.)	2,000	

Physiological activity of these microbes brings about material and energy changes which transform *potential fertility* to *active fertility*. The soil in serving as a culture medium for microorganisms and higher plants functions as a manufacturing plant, a storage plant, and a disposal plant. In this respect it resembles a living organism.

The Rhizosphere or root zones are especially favorable to development of bacteria ; 75 to 90% of the total microbial population of a soil occurs in this zone. This is attributable to the enormous extent of root systems and their root hairs, which have a calcium-pectate surface layer. A study at Iowa University by Dittmer (2) of one winter rye plant grown in 2 cu. ft. of silt loam soil, bulk density 1·30, revealed the following :

13,800,000 roots, total length 385 miles ; 2554 sq. feet surface area.
14×10^9 root hairs, total length 6600 miles, total area 300 sq. feet.
Total root surface exposed to soil, 6875 sq. ft.

The total external surface of the 80 shoots with their 480 leaves was 51·38 sq. ft. Surface of the subterranean parts was therefore 130 times that exposed by the top.

Soil, 145 lbs, surface area 110 sq. meters per gram, had a total surface of 70×10^6 sq. ft. (1607 acres). Thus the total root surface of the one rye plant was equivalent to only 0·01% of this surface area of the soil in which grown. Hence, roots make poor contact with the soil.

One sugar beet grown on irrigated sandy loam soil at Moses Lake, Washington, was found to have roots extending downward 7 ft., and to have 10,000 sq. ft. total surface area. The evaporation rate was 0·25″ water per 1 sq. ft. of soil per day from 8 a.m. to 6 p.m., equivalent to 14×10^9 water molecules/sq. cm/second entering the roots. The fresh weight increased at a rate of 50 g per day.

The general significance of the localized zone of soil microbial activity in the rhizosphere may be summarized as follows :

1. Plant roots not only support larger numbers of microorganisms than the surrounding soil but they also exert a selective action, favoring physiologically more active forms as well as chromogenic and gram-negative types of bacteria.
2. Competitive and synergic forces occur in the rhizosphere and certain microbial communities eventually predominate. The bacterial flora of the rhizosphere of plant varieties resistant to soil-borne disease differ from the flora supported by plants susceptible to the disease. This suggests that the selective action of root excretions on the saprophytic soil microflora may be associated with either disease resistance or disease susceptibility. Attempts to control soil-borne diseases, such as potato-scab and strawberry root rot, by altering the biological equilibrium in the rhizosphere so as to favor harmless or beneficial organisms and inhibit undesirable forms have met with some success.
3. Nutritional characterization of the microflora of the soil and of the rhizosphere has shown that organisms requiring amino acids for maximum growth are selectively stimulated in the rhizosphere, whereas bacteria with more complex nutritional requirements are relatively more abundant in soil at some distance from the root. While microbial antagonisms developed in the soil and in the rhizosphere are undoubtedly of considerable ecological significance, the synthetic activities of microorganisms and their nutritional response involving vitamins, amino acids and growth factors may be just as important. Many practical and theoretical implications are apparent.

Biological pressure is a distinct geochemical surface phenomenon, an important factor in soil development. Biological pressure expresses a ratio of the amount of living matter, or a sum total of the bodies of living matter, per square unit of the surface area. It is limited by physical conditions, and its natural geographical distribution is a function of climate and other factors of geophysical environment. A certain natural balance between physical capacity and biological pressurization exists in any given natural region. This imposes its influence upon all soils, but especially upon the fundamental characteristics of zonal soils. The amount of humus in soils ranges from less than one percent to as much as about 20 percent according to the type of soil and the degree of its biological pressure.

Soil science is concerned with the soil body as found in nature. Its various branches include categories like those used to describe bacteria :

Morphology—physical structure, horizons, mechanical composition, microscopic appearance of exposed profile surfaces.

Staining reactions—microscopic study of thin and stained sections.

Chemistry—mineralogical and chemical composition. C and N are especially important.

Cultural characters—Topography, exposure, drainage.

Physiology :

Effect of environment or soil-creating forces.

Active—climate, biosphere, biological pressure.
Passive—parent material, relief.

Effect on environment :

Moisture, temperature, etc.
Ground cover, biosphere.
Action on creating forces.

Classification—Nomenclature and taxonomy—soil survey and land classification.

Soil microbiology is concerned primarily with the physiology of the soil body The studies proceed along two fairly distinct lines : (1) the isolation and study of various species in pure culture ; (2) the study of certain physiological activities, such as nitrification, respiration, and nitrogen fixation, in the soil itself, directly or indirectly, with and without appropriate additions to enhance these activities. Studies in this second category concern over-all *soil physiology*.

Soil bacteriology gradually evolved into soil microbiology, which now is concerned not only with bacteria but also with molds, algae, protozoa, and viruses in relation to soil fertility. The next step in the evolution will be the establishment of soil physiology as a separate subscience in pedology. Already soil microbiologists can be fairly well separated into those who emphasize study with pure cultures, and those who investigate specific functions as they occur mainly in the natural environment of the soil.

Environmental Factors influencing the soil as a culture medium

These are the same as those influencing any living organism. Almost any substance and any microorganism may occur in the soil. The relative numbers and activity of the various soil microorganisms and their resultant influence upon soil fertility is determined by the shifting ecological equilibria attained under influence of the following major factors :

Moisture

Radiant energy : temperature, light.

Aeration. Supplies O_2, N_2, CO_2; removes excess CO_2

pH

Food supply. Organic and inorganic. Nutralites.

Inhibiting factors—extremes, positive or negative, or any other factor.

Biological factors—antibiosis, metabiosis, symbiosis, pathogenicity, parasitism.

Each of these factors is influenced by a variety of subfactors imposed by climate, soil type, and vegetation. For example, moisture is influenced by rainfall,

drainage, soil texture and structure, organic matter, tillage, wind, and even soil color as affecting temperatures and its effects on reaction rates, pH, and viscosity. All interact and induce dynamic changes. Equilibria attained are transient and vary from one microclimate to another. The net ecological effect is an integration of all these interactions and influences, among which those of soil microbes are fundamental (1) (3).

Optimum soil conditions for microorganisms and crop plants in general agriculture :

Moisture—approximately 50% of moisture holding capacity (m.h.c.).

Temperature—25 to 30°C

Aeration—optimum with moisture near 50% m.h.c.

pH—near 7

Food supply—balanced, with no excess to cause loss, antagonism or unavailability ; no deficiencies.

Organic matter optimum, neglecting plant food, is determined by its effect on physical conditions.

C : N=25 :1 is optimum for fresh organic matter.

C : N of humus generally near 10 : 1

Biological factors often can be altered for economic profit by artificial inoculation or by sterilization. The ecological importance of soil organisms can be largely summarized in two words : "*soil fertility.*" Soil fertility is expressed in crop-producing power under given climatic conditions. In a given soil the total fertility consists of potential fertility and active fertility. Active fertility embraces all plant nutrients which are immediately available ; potential fertility is represented by plant food elements contained in insoluble minerals, organic residues and humus, and gaseous nitrogen and carbon dioxide of the atmosphere. It is the function of soil microorganisms to render this extensive store of potential fertility active.

The outstanding common characteristic of the total flora and fauna is the power to continuously transform matter and enargy. As a result the various food elements are dynamically transformed in cycles which maintain circulation of these elements in nature and prevent their permanent isolation in organisms after death. Bacteria play a large part in these transformations for two reasons : (1) they grow and transform matter more rapidly than other organisms ; (2) they perform reactions impossible to other organisms.

Two basically distinct types of nutrition separate all living things into two classes from the standpoint of natural economy. Those of the first class are strictly mineral feeders : they synthesize organic tissue from carbon dioxide ; they are producers, constructive and independent of other organisms. These are the autotrophes and they include all chlorophyll–containing plants, photosynthetic bacteria, and certain chemosynthetic bacteria. The other class are the heterotrophes; they are biological feeders, requiring organic food previously synthesized by some other organism. In nutrition they are consumers, destructive, and dependent. They embrace all animals, the fungi, and most bacteria.

The soil bacteria and other microbes which attack plant and animal remains break them down into simple substances which plants can use. Like animals they are destructive feeders. They bring about decomposition or decay which is an essential feature of life. From the standpoint of plant nutrition this may be considered a predigestion of plant food. It is performed by many unspecific

bacteria and by a few specialized bacteria capable of attacking particular substances. In some instances the bacteria act as scavengers in decomposing materials that might be toxic to plants.

Building-up processes in the soil are brought about by bacteria, which may be considered constructive feeders. Two types may be recognized: (1) strictly mineral feeders, which like plants, build their organic substance from carbon dioxide and water; (2) semi-mineral feeders or nitrogen fixers which require complex carbonaceous food, but can utilize nitrogen in elemental form. The significance of strictly mineral feeders lies in their ability to obtain energy by oxidizing simple mineral substances such as hydrogen, methane, ferrous iron, and especially ammonia to nitric acid and sulfides or sulfur to sulfuric acid. This action not only changes decomposition products to available plant food but also produces solvent action on soil minerals, rendering them available.

The ecological significance of these two groups can be appreciated from a brief consideration of the cycles of carbon and nitrogen (2). In the carbon cycle, carbon dioxide from the atmosphere is converted by autotrophes into organic compounds of high energy content. Photosynthetic organisms obtain energy for this transformation from the sun's rays. The autotrophic bacteria derive energy from oxidation of certain elements, such as sulfur or hydrogen, or from oxidation of simple compounds such as ammonia, hydrogen sulfide, or carbon monoxide. Heterotrophes consume organic substance previously elaborated by autotrophes and other heterotrophes; this biological material is utilised for both structure and energy, the greater proportion being oxidized for energy and therefore yielding much carbon dioxide, which returns to the cycle.

In the nitrogen cycle proteins yield ammonia upon decomposition by a wide variety of bacteria, actinomyces and molds. Ammonia is oxidized to nitrite and nitrate by autotrophic nitrifying bacteria. Nitrate, as well as some ammonia, is assimilated by plants and microbes and converted to protein, thus completing the cycle. Protein metabolism by animals extends the cycle without greatly altering the fundamental mechanism.

An additional phase of outstanding importance is nitrogen fixation. This is the assimilation of elemental nitrogen and is an ability possessed only by a few bacteria, mainly heterotrophes, and certain blue-green algae. Non-symbiotic fixation is carried on by *Azotobacter* and certain species of *Clostridium*. The nitrogen is converted by some mechanism to ammonium and to amino acids, and finally to cell protein; on death of the cell this reenters the cycle and becomes subject to ammonification. Species of *Rhizobium* carry on fixation only when living symbiotically in nodules on roots of leguminous plants, much of the fixed nitrogen being immediately available to the host. Of the total nitrogen fixation by both *Azotobacter* and *Rhizobium* a considerable part is liberated in soluble extracellular organic form during the life of the cell; some ammonium is also liberated. Thus nitrogen-fixing bacteria convert the generally unavailable gaseous nitrogen into immediately available compounds as well as into nitrogenous tissue which must later be decomposed by other organisms before becoming active in fertility.

Losses occur by erosion, leaching of nitrate, volatilization of ammonia under certain conditions, and by denitrification. These losses are especially important because available nitrogen is most frequently the limiting plant nutrient in soils. An estimate of the annual nitrogen balance in the United States, based upon data available in 1957, is presented in Figure 3. Although outdated, it serves to emphasize the need for erosion control, cultural methods and forms of fertilizer to reduce leaching, and increased use of inoculated legumes.

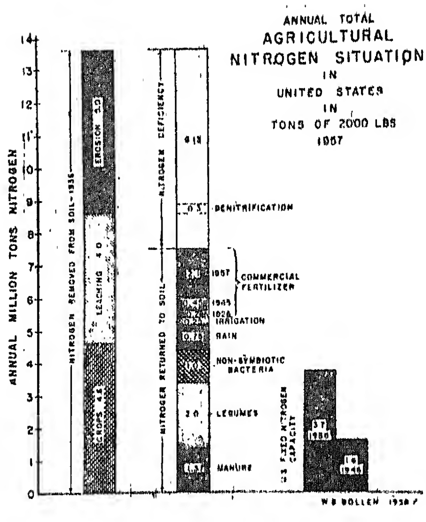


Fig. 3

Decomposition of plant and animal remains is an essential feature of the circulation of nutritional elements in nature. In effect it constitutes a mineralization of organic matter. Carbon is returned to circulation as carbon dioxide, nitrogen is again made available as ammonium and nitrate ; sulfur is liberated as sulfide and converted to sulfate, and other essential constituents reappear in the form required by plants. Because organic remains are of mixed composition they are acted upon by various species of microorganisms and exhibit several well-defined stages of decomposition. In these stages different groups of microorganisms predominate as part of the substrate is more or less rapidly and completely decomposed, part is reassimilated, and part is resistant and very slowly decomposed. Depending on the frequency with which fresh remains appear on or in the soil the several stages of decomposition are more or less concomitant.

Starting with fresh material there is first a stage of rapid decomposition in which the readily available substences are utilized by many heterotrophic microorganisms. Molds and spore-forming bacteria are especially active in consuming the proteins, starches and cellulose. The relatively large amount of carbon dioxide liberated is important for its solvent action on soil minerals. Development of free-living nitrogen-fixing bacteria is stimulated by the supply of carbohydrate, which they utilize chiefly for growth energy. By-products which are formed include ammonia, hydrogen sulfide, hydrogen, and organic acids, alcohols and other incompletely oxidized substances. In the second stage these substances are reassimilated in two phases : an autotrophic phase, wherein autotrophic bacteria oxidize the ammonia, hydrogen sulfide, and hydrogen : and a heterotrophic phase in which the organic byproducts liberated in the first stage are utilized by a wide variety of microorganisms.

A strong solvent action on soil minerals results from the nitric and sulfuric acids produced in the autotrophic phase of reassimilation. Development of the heterotrophes in this stage is influenced not only by the energy materials but also by the nitrogen compounds available. There is competition for nitrogen between higher plants and microorganisms carrying on the decompostition ; the balance is

determined by the carbon-nitrogen ratio of the original plant or animal residue. If this material has a nitrogen content of about one percent all the nitrogen is consumed by the microorganisms, and in addition they compete with higher plants for more available nitrogen from the soil so long as oxidizable carbon compounds remain. An extended nitrogen starvation thus may result : this may be corrected by addition of inorganic nitrogenous fertilizres. When the nitrogen content is from 2 to 2·5 percent, only a temporary nitrogen starvation occurs and is followed by liberation of ammonia. With a higher percentage of nitrogen the requirements of the organisms active in the decomposition are more than satisfied and ammonia is liberated through the process.

The final stage of decomposition is the stage of humification. This is characterized by the formation and gradual continual decomposition of the humus-complex. Nitrogen assimilated by microorganisms is reassimilated and repartitioned until much of it accumulates as protein of dead bacterial cells. Bacterial protein is resistant to decomposition and some of the nitrogen of humus may be in this form. The non-nitrogenous portion of humus is composed largely of lignins, hemicellulose, and various other resistant substances, but the lignin is of peculiar importance because it exerts a specific effect in nitrogen conservation by binding amino acids and proteins. The amount of protein or other nitrogen compounds bound, whether of bacterial or other origin, depends upon the supply, but the bound nitrogen is always more resistant to liberation. Only actinomyces and certain non-spore-forming bacteria which comprise an autochthonous microflora can attack lignoproteinate or its equivalent and other humus complexes. As a result the nitrogen is only slowly but continuously liberated as ammonia ; this maintains for higher plants a supply of available nitrogen that bridges the intervals between additions of fresh organic residues.

Soil microorganisms are active in four zones of decomposition : surface debris, turned-under residues, root evelopes, and humus. Each is of peculiar significance. Infiltration of the end products of surface decomposition influences soil formation and morphology ; this is strikingly shown in development of the podsol profile. Artificial incorporation of crop residues and manures by cultural practices distributes and hastens mineralization to the immediate advantage of plant growth. In soils upon which plants are growing, a large proportion of the microflora is confined to a narrow zone about the roots. This zone, the rhizosphere, is of major importance in the nutrition of higher plants for here are impressed a series of relationships ranging from symbiosis, mutualism, and stimulation to inhibition, toxicity, and parasitism. Humus, under natural conditions, is distributed from the soil surface downward in a decreasing concentration and to a depth characteristic of the soil type ; this affects accordingly the distribution and activity of the autochthonous microflora.

The ecology of soil microorganisms is largely a matter of microbial physiology. In this connection the bacteria are of particular interest because from the evolutionary standpoint their minute unicellular structure has strictly limited their morphological development. Physiologically, however, they exhibit a wide evolution in nutritional level resulting from development of enzyme systems capable of utilizing various products in increasing variety.

Autotrophic bacteria present the most primitive nutritional level. They require only mineral nutrients, synthesizing complex organic compounds from carbon dioxide and water. They are able to grow on bare rock and contribute to the formation of soil and accumulation of organic matter. As a result they pave the way for development of heterotrophes.

An intermediate or transitional nutritional level is exhibited in the facultative autotrophes, typified by certain sulfur-oxidizing and hydrogen-oxidizing bacteria which can metabolize either carbon dioxide or biological carbon compounds. This faculty is probably more widespread than it is apparent. Only recently has it been discovered that *Escherichia coli*, the colon bacillus, heretofore regarded as a typical dependent heterotrophe, is able to grow autotrophicly and obtain energy by oxidizing hydrogen. Facultatively autotrophic bacteria may be looked upon as representatives of the first physiological types which arose by virtue of the nutritional possibilities offered by the simultaneous presence of organic matter and primitive mineral energy sources.

The obligate heterotrophes present a series of higher levels of nutrition. Opportunity provided by the great variety of carbon compounds available from dead organic matter incited the development and use of new reactions for utilization of these materials for both energy and structure. Numerous species have been evolved on the basis of these nutritional possibilities. Further differentiation has taken place with respect to nitrogen source ; the level has raised from gaseous nitrogen, ammonium, and nitrate to amino acids. Many of the saprophytic bacteria are facultative in this respect, while some of the pathogens are highly exacting and require specific amino acids or even complexes thereof.

The nitrogen-fixing bacteria present extreme examples which, while they require carbon compounds synthesized by other organisms, can elaborate protoplasm with elemental nitrogen. The symbiotic nitrogen fixers, *Rhizobium*, and certain *Streptomyces*, have evolved to higher nutritional requirement because they have lost the ability, possessed by free-living forms, to synthesize an essential respiration coenzyme. At the opposite extreme are certain photosynthetic bacteria and blue-green algae which not only fix nitrogen but also assimilate carbon dixoide by photosynthesis.

Restriction of synthetic ability leads finally to parasitism and dependence upon living tissue for necessary growth requirements, including growth factors or "bacterial vitamins". The highest nutritional level is thus exemplified by the exacting requirements of many animal pathogens.

An apparent anomaly is presented by this evolution in adaption to available food. The most highly evolved bacteria have the most complex food requirements ; by virtue of this they possess the simplest metabolic mechanism. Autotrophes, in contrast, being capable of utilizing the most simple food, must possess the most complex nutritional mechansim.

Microorganisms have made possible the soil and its products ; in turn, the soil and its products have made possible the microorganisms. These are vast resources for which adequate control measures must be devised and applied to ensure man's first fundamental right-freedom from hunger.

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Uptake of phosphorus by maize at 3 different stages of its growth

By

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It has been observed that low crop production is more often due to the lack of phosphorus than that of any other element. Phosphate is essential for the healthy growth of plants and its adequate supply to plant helps to ensure rapid growth and early maturity (1 and 2). S. Gerickel as reported by S. Das (3) Ex-chief Chemist, I. A. R. I. New Delhi came to conclusion that 1 Kg. of phosphoric acid assimilated by the plant produced in grain 31·5 Kg of plant mass, so this is tenta-mount to saying that the yield drops most, when insufficient phosphoric acid is present in the soil.

Glover (4) noted that the consumption of phosphorus and of nitrogen increased with the growth of the maize upto the age of silking and tesselling. Phosphorus uptake was equally high during setting and ripening of grain. Wither (5) using P^{32} concluded that lower stems and leaves contained more P^{32} than those above the ear while leaves showed higher values than the stems. Tassels maintained constant P^{32} after initial absorption. Husks contained more P^{32} than the cobs. Kerneals contained the greatest amount of phosphorus.

During the present investigation the uptake of phosphorus by maize at 3 different stages of its growth *i.e.* 25 days, 50 days and 75 days after germination has been studied.

Three levels of phosphorus in the form of superphosphate (16 % P_2O_5) ammonium phosphate (48 % P_2O_5) and Bone meal applied along with F. Y. M.

Methods and Materials

Soils.—Surface soil (0–6″) from Varanasi. Mixed air dried and powdered to a fine state. The composition of the soils is given in table.

Phosphates.—Superphosphate, Bone meal and ammonium phosphate were used in the experiment at rate of 0, 40 and 80 lbs of P_2O_5 per acre.

Addition of F. Y. M.—F. Y. M. at the rate of 0, 10, 20 and 40 tons per acre was applied.

Analysis

Plant analysis for total phosphorus was done by A. O. A. C. method (6) and for inorganic phosphorus in soils was carried out by Dickman and Bray (7) method.

Soil-analysis

Loss on ignition	3·964
HCl (insoluble)	85·721
Sesquioxides	9·075
Fe_2O_3	3·985
Total P_2O_5	0·0794
Total CaO	0·9842
Total K_2O	0·946
Total MgO	0·5216
Total Carbon	0·5738
Total Nitrogen	0·0550
pH	7·8

Results and discussion

TABLE 1

Analysis of plants showing total uptake of phosphorus per pot of maize at the 3 stages of growth

S. N.	Treatment	Mgm P mean value		
		Ist stage	IInd stage	IIIrd stage
1	O_1S_1	55·193	59·06	71·24
2	O_1S_2	85·46	95·00	100·56
3	O_1A_1	60·64	61·01	76·66
4	O_1A_2	93·33	102·14	109·34
5	O_1B_1	53·31	85·96	57·57
6	O_1B_2	69·53	80·31	80·66
7	O_2S_1	56·459	64·954	80·70
8	O_2S_2	93·55	99·41	115·66
9	O_2A_1	61·08	67·82	83·04
10	O_2A_2	96·89	110·02	123·98
11	O_2B_1	53·75	60·29	60·19
12	O_2B_2	80·60	88·25	89·09
13	O_3S_1	61·16	68·98	87·78
14	O_3S_2	94·02	106·29	121·68
15	O_3A_1	66·37	71·61	87·56
16	O_3A_2	99·23	115·70	136·10
17	O_3B_1	56·98	63·29	64·78
18	O_3B_2	83·26	89·93	98·56
19	O_0P_0	36·85	45·72	48·99

O_1 = F. Y. M. 10 ton per acre, O_0 = No F. Y. M.
S_1 = Superphosphate at the rate of 40 lbs P_2O_5 per acre, P_0 = No P
S_2 = Superphosphate at the rate of 80 lbs P_2O_5 per acre.
A_1 = Ammonium phosphate at the rate of 40 lbs per acre.
A_2 = Ammonium phosphate at the rate of 80 lbs P_2O_5 per acre.
B_1 = Bone meal at the rate of 40 lbs per acre.
B_2 = Bone meal at the rate of 80 lbs P_2O_5 per acre.

TABLE 2

Analysis of maize plants showing phosphorus uptake at its 3 stages of growth

S. N.	Treatment	Percentage of P_2O_5 1st stage	IInd stage	IIIrd stage
1	O_1S_1	0·53	0·36	0·244
2	O_1S_2	0·63	0·416	0·320
3	O_1A_1	0·54	0·343	0·256
4	O_1A_2	0·65	0·436	0·326
5	O_1B_1	0·51	0·323	0·206
6	O_1B_2	0·57	0·406	0·243
7	O_2S_1	0·54	0·366	0·276
8	O_2S_2	0·64	0·423	0·323
9	O_2A_1	0·53	0·356	0·273
10	O_2A_2	0·66	0·460	0·336
11	O_2B_1	0·52	0·346	0·236
12	O_2B_2	0·62	0·403	0·320
13	O_3S_1	0·55	0·343	0·290
14	O_3S_2	0·62	0·430	0·343
15	O_3A_1	0·531	0·356	0·270
16	O_3A_2	0·68	0·370	0·353
17	O_3B_1	0·536	0·323	0·240
18	O_3B_2	0·626	0·403	0·296
19	O_0P_0	0·503	0·323	0·220

TABLE 3

Analysis of residual soils for available phosphorus after the harvest of the maize plants

S. N.	Treatment	$\%P_2O_5$	Total P/(%) in gm.	Available P/acre
1	O_1S_1	0·016	0·364	32·00
2	O_1S_2	0·028	0·637	56·00
3	O_1A_1	0·018	0·4094	36·00
4	O_1A_2	0·030	0·6285	60·00
5	O_1B_1	0·012	0·273	24·00
6	O_1B_2	0·200	0·455	40·00
7	O_0P_0	0·008	0·182	16·0

S. N.	Treatment	$\%P_2O_5$	Total P/(%) in gm.	Available P/acre
8	O_2S_1	0·017	0·3867	34·0
9	O_2S_2	0·028	0·6461	57·6
10	O_2A_1	0·018	0·3931	37·2
11	O_2A_2	0·032	0·7280	64·0
12	O_2B_2	0·013	0·2957	26·0
13	O_2B_2	0·024	0·5232	48·0
14	O_0P_0	0·07	0·1774	15·6
15	O_3S_1	0·018	0·4095	36·0
16	O_3S_2	0·029	0·6043	54·4
17	O_3A_1	0·019	0·4340	38·2
18	O_3A_2	0·032	0·7472	65·6
19	O_3B_1	0·013	0·3048	26·8
20	O_3B_2	0·024	0·5551	49·0
21	O_0P_0	0·007	0·1683	14·8

It is evident from the above tables that all the treatment combination with 10 tons, 20 tons and 40 tons of F. Y. M. are significant. Ammonium phosphate stood first in order of uptake and signifies the maximum availablity with this fertilizer and this particular type of soil. Superphosphate can be categorised less effective than ammonium phosphate but the bone meal is of least importance from the solubility and availability point of view.

It has also been observed that availability and uptake of phosphorus occur invariably at different stages of growth by maize. Availability and uptake were determined at three stages of growth *viz,* 25, 50 and 75 days after germination. This can be discussed in the following heads.

First stage—The yield of dry matter increased with increase in organic matter levels. The maximum yield was obtained with 40 tons of organic matter. The total uptake of phosphorus increased with higher levels of organic matter. The first stage *i.e.* 25 days after germination, showed higher percentage of phosphorus uptake as compared to second and third stages.

Second stage—The total phosphorus content of plants increased with increasing dose of F. Y. M. But the percentage phosphorus uptake has been found to reduce as compared to first stage. The results obtained are in conformity with the results obtained by McGregor (8) and Dutta and Goswami (9).

Third stage—The total uptake of phosphorus, significantly increased at 3rd stage also, but the percentage of phosphourus uptake decreased as compared to first and second stages of growth. The order of efficiency for organic matter based application is found to be O_3, O_2, O_1, O_0.

Summary

Three levels of phosphorus in the form of superphosphate, ammonium phosphate and bone meal were applied along with F. Y. M. to maize in pots. 25 days, 50 days and 75 days after germination, plants were analysed in order to study the uptake and availability of phosphorus.

It was observed that utilization and uptake of phosphorus by the plants were maximum at 25 days and it decreased with age and maturity. Though the total uptake of phosphorus at second and third stages *i.e.* after 50 and 75 days respectively has increased from the first stage (was more than the first stage) but the percent uptake and utilization was maximum in the early stages of growth. Ammonium phosphate has shown better uptake by the crop as compared to the same dose of superphosphate and other phosphatic fertilizers.

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Studies on the Microbial Population of the Soil

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Introduction

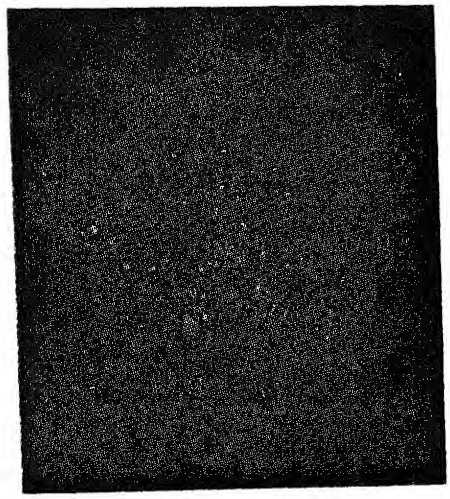
Regarding the activity of bacteria, their multiplication and its impact on soil fertility the first valuable report was of Caron (1895) who showed that increase in number of microorganisms in the soil resulted in increased farm output. Later on the importance of microbial population studies as an index of soil fertility was emphasised by Remy (1902), Löhnis (1904–1905) and Waksman (1922). The study of the environmental factors such as soil depth, temperature, soil moisture and weather conditions etc., involving changes in the bacterial population of the soil was taken up and valuable data were presented by Remy (1902), Hiltner and Störmer (1903), Cutler, Crump and Sandon (1922), Winogradsky (1924, 1925), Fehér (1933), Fehér and Frank (1937, 1938), Vandecaveye and Katznelson (1938), Klauss (1940), Burrichter (1958) and Seifert (1960*a*). A significant correlationship between bacterial number and "organic matter" of the soil has been pointed out by Jensen (1934), Gray and McMaster (1933), Gray and Taylor (1935) and Gray and Wallace (1957*a*). Gray and Wallace (1957*b*) in another paper drew a parallel between the bacterial number and CO_2 evolution.

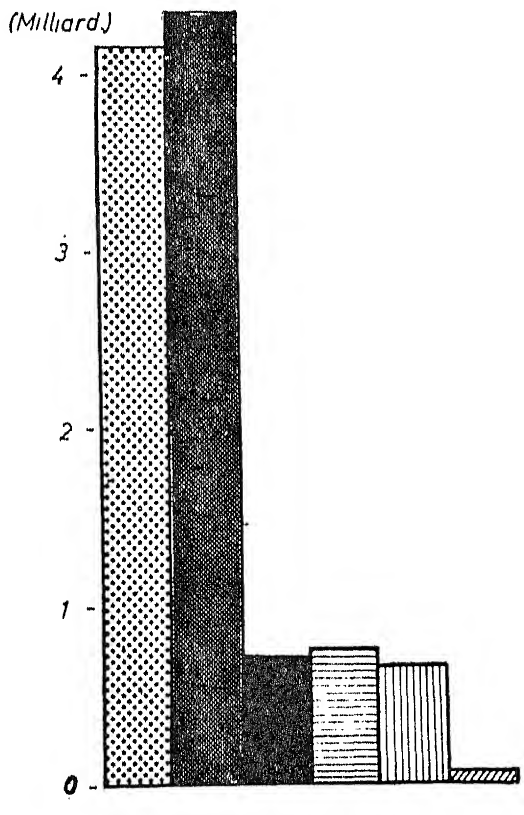
Use of fluorescent microscopy in soil microbiology :

From all these studies and a host of others which find their mention later on in this article it becomes evident that the study of microbial population in the soil alongwith its fluctuations are of utmost importance for assessing soil fertility. As such a fluorescent microscopic method was developed by Rouschal and Strugger (1943) for making routine-analysis of the soil for their bacterial population. This method was later on standardised and improved upon by Strugger (1949), Burrichter (1953) and Haber (1958).

The principle involved in fluorescent microscopic technique is that of staining of a definite amount of soil preferably 1 g of soil in a suitable concentration of "Acridinorange" a fluorescent dyestuff which has got the property of differentiating the living bacteria, fungi and actinomycetes with that of their dead counterparts. The dilution grade of the "Acridinorange" has to be ascertained earlier for it varies with different types of soils. Treated with the fluorescent dye Acridinorange and observed in the blue-light of the fluorescent microscope the bacteria on the soil particles appear as greenish yellow shining objects with red background of the latter. The green fluorescing bacteria could easily be distinguished from the dead ones which emit dull red fluorescence and also from the soil particles which too are dull red in appearance, (Fig. 1). This method is more accurate, reliable and time-saving. Its utility has been emphasised by many soil microbiologists and its practical application did find its way in the laboratories of many of the scientists. The Strugger's method of determining the amount of bacteria in the soil has found active support from Tschan and Augier (1949). Lehner and Nowak (1957), Stöckli (1959) and Nowak and Netzsch-Lehner (1960), A modification of Strugger's method known as Cholodny-Strugger–combination method was introduced for studies of microbial sociology by Lehner, Nowak and Seibold (1958).

Fig. 1. Green fluorescing bacteria. In the background are dull red soil particles. Acridinorange staining. Ortholux (Leitz) fluorescent microscope. Magnification 700 ×.





Str = Strugger

Ch-Str-Komb. = Cholodny-Strugger Combination

Cn. = Conn.

Win. = Winogradsky.

J. u. M. = Jones and Mollison.

Ko. = Koch-plate (Agar-plate).

Fig. 2. Amount of bacteria in soil as estimated through simulataneous application of different methods. Milliard. = 1000 × Million.

Comparative study of the different methods used for quantitative estimation of soil bacteria :

Data of experimental results found by the author while comparing the merits of certain important methods employed for bacterial estimation in the soil is presented here. The methods employed here were *a*) Strugger's (1949) ; *b*) Jones and Mollison (1948) ; *c*) Cholodny–Strugger-combination method (Lehner, Nowak and Seibold 1958) ; *d*) Conn (1918) ; *e*) Winogradsky (1925) and *f*) Koch-plate method (Agar plate method) (Koch 1881). As the soil is a dynamic thing and is subjected continually to changes it was essential to employ all the methods simultaneously on the same soil sample and also to get the results in shortest possible time. The soil sample used was a garden-soil obtained from the campus of the Botanical garden of the University of Münster. The methods used have been described by the various authors. In the Agar-plate method Beef-extract was used as a nutrient medium.

As it would appear from the enclosed table 1 and the graphic representation in Fig. 2, in comparison to the Strugger's fluorescent microscopic method the bacterial amount obtained by all the other methods are considerably low *e.g.*

Strugger : Jones and Mollison	=	6 : 1
Strugger : Conn	=	6 : 1
Strugger : Winogradsky	=	6 : 1
Strugger : Strugger–Cholodny–combination	=	1 : 1
and Strugger : Koch–plate	=	145 : 1.

Of all the methods used the highest bacterial numbers are obtained by fluorescent microscopic method of Strugger. The most difficult part of counting and differentiating the living bacteria from soil particles can be successfully achieved by the application of this method only. The disadvantage of this method as also of other direct methods is that one can not identify the microorganisms.

The Cholodny–Strugger–combination method is interesting in the sense that it gives not only high bacterial numbers but also presents in an undisturbed form as shown in Fig. 3 the microbial society as it exists in the soil. An exact qualitative analysis in regard to the identification of the soil microorganisms is also possible for according to Hopf (1950) one can isolate the organisms from the Cholodny plate and inoculate them on Agar-plates. Because of the fact that it is time-consuming it cannot be used as a method for routine-analysis.

Fig. 3. Cholodny–Strugger–Combination method. A colony of green fluorescaing bcteria (1·6 × 0·5/). Magn. 1100.

As is evident from the Fig. 2 and Table 1 all the other methods namely Conn, Winogradsky and Jones and Mollison have almost identical values and give six times less the value of the fluorescent microscopic method. It is because of the fact that in all these methods where ordinarily stains have been used it is practically impossible to make a distinction between bacteria and the identically stained basophilic soil particles. Moreover the distinction between living and the dead microorganisms cannot be drawn at any stage.

Agar-plate method has been very widely used by many scientist. It has its own advantage for this method only can help in the identification of the soil microorganisms. For quantitative purposes it is most unsuitable and has its limitations for there is no single nutrient medium which can embrace all the different kind of microorganisms and could serve them with proper nutrition. In fact the soil microorganisms are highly specific and nutritionally selective.

In fact for purely routine-work of quantitative analysis of microbial population in the soil the most suitable method is Strugger's fluorescent microscopic method. For study of microbial ecological problems Cholodny-Strugger-Combination method should be employed and for identification purposes nothing but the Agar-plate method is the answer.

Microbial population as an index of soil fertility :

In the recent years it has also been possible once again to assess the quality and the type of the soil on the basis of bacterial quantity as estimated with the help of the fluorescent microscopic method of Strugger. The important references in this connection are the works of the following scientists: Burrichter (1953, 1955); Feldmann (1956) ; Jagnow (1958 ; Haber (1958, 1959) and Seifert (1958).

Burrichter (1953) pointed out that a direct relationship existed between the soil type and its bacterial content and with possible exception of heavy clay soils, a soil classification with fertility as an index running parallel to bacterial amount could be made. Burrichter (1955) went further to establish that with the increase in the clay content the bacterial amount increased and that they were lowest in sands and highest in loams though slightly less high in clays. In arable soils the bacterial maxima were in sandy loams. Humus content and bacterial population were much more highly correlated in arable than in grassland soils. No correlationship could however be established between pH values of soils and bacterial numbers. High bacterial population could influence a high yield of rape crop.

Burrichter (1954) while studying the succession of natural forest under Humus-podzolic soil from dry dwarf-shrub stage through dry Birch-bush stage and finally a Oak-Birch community found that a definite correlationship existed between their succession and bacterial amount in the soil. As the climax in Oak-Birch community reached the bacterial amount recorded its maximum. According to Burrichter (1954) the quantitative analysis of the bacteria in the soil could predict the fertility of a forest soil as well and also impress the favourable or unfavourable influence of different timber trees on the soil. In Czeckoslovakia Seifert (1960 *b*) also undertook the study of the quantity of the microorganisms in the soils of different plant communities. Jagnow (1958) suggested that the bacterial amount in the soil reacted more to the type of the soil and its humus percentage than to the plant community cover.

TABLE 1

Number of bacteria of a soil estimated

Name of the Method employed	Description of the slide	Dilution	Weight of the soil films (in g)	Number of colonies per petri dish	Number of bacteria per microscopic field	Standard Deviation	Co-efficient of Variability	Number of bacteria as per moist weight	Average
Strugger	Without $\frac{1}{3}$ addition	–	–	–	2·05	–	–		3340·0
	With $\frac{1}{3}$ addition	–	–	–	–	–	–		4360·0
Jones and Mollison	–	–	–	–	2·54	–	–		528·9
Cholodny–Strugger–Combination Method	1.	–	0·0020	–	9·34	–	–	3483·0	
	2.	–	0·0021	–	7·97	–	–	2851·0	
	3.	–	0·0038	–	11·06	–	–	2394·0	3497·2
	4.	–	0·0021	–	9·94	–	–	3985·0	
	5.	–	0·0018	–	9·85	–	–	4503·0	
Conn	1.	–	–	–	12·65	± 7·87	62·20	524·7	
	2.	–	–	–	14·70	± 8·42	57·30	612·2	
	3.	–	–	–	14·00	± 9·12	65·14	563·0	571·5
	4.	–	–	–	13·60	± 6·82	50·12	566·4	
	5.	–	–	–	14·25	± 6·04	42·37	591·4	
Winogradsky	Sediment 1	–	–	–	5·32	± 2·77	52·60	520·6	
	Sediment 2	–	–	–	7·68	± 3·53	45·93	633·0	
	Suspension 2	–	–	–	8·20	± 4·11	50·11	673·8	
	Sediment 3*a*	–	–	–	6·20	± 3·86	62·20	516·4	605·8
	Suspension 3*a*	–	–	–	9·16	± 4·59	50·20	747·0	
	Sediment 3*b*	–	–	–	5·40	± 3·91	72·50	449·8	
	Suspension 3*b*	–	–	–	9·64	± 5·41	56·10	779·6	
Agar-plate method	–	1×10^{-4}	–	338·0	–	± 49·60	14·65	3·4	
	–	1×10^{-5}	–	144·9	–	± 23·41	16·15	14·5	
	–	2×10^{-6}	–	60·9	–	± 9·89	16·25	30·4	19·7
	–	1×10^{-6}	–	23·4	–	± 5·46	24·18	23·4	
	–	1×10^{-7}	–	2·7	–	± 0·82	30·40	27·0	

through the application of different methods

in 1 g of the soil in (Millions) As per dry weight	Average	The amount of bacteria in proportion to the value of Strugger's Method	Moisture Content of the soil	Statistical Analysis on the basis of Neyman's Formula s^2	m_1	m_2	X^2	DF	P in %
	4125·0								
	5375·0			4·34600	1·83030	0·48642	4·26182	4	38·40
	680·0	1 : 6		7·67690	1·25590	2·02240	9·93779	7	21·79
4740·0									
3510·0									
2945·0	4317·0	1 : 1							
4790·0									
5600·0									
645·0									
754·0									
693·0	703·8	1 : 6	18·80						
699·0									
728·0									
642·0									
779·0									
829·0									
636·0	745·7	1 : 6							
921·0									
553·0									
958·0									
4·2									
17·8									
37·6	24·1	1 : 145							
28·8									
33·1									

Studies of the effect of organic fertilizers etc. on microbial population :

Through the application of the fluorescent microscopic technique the influence of the organic fertilizers on the bacterial content of the soil could be ascertained by Feldmann (1957). The effect of "Flotal" on the biological state of the soil was studied by Siegel and Diesselkamp (1958). They found that there was considerable increase in bacterial number in Flotal-treated soils and improvement atleast in the structure of the latter. Kuron, Homrighausen and Rohmer (1959) studied the effect of surface erosion on the powdery clay soils and its influence on bacterial content. Due to surface erosion strong variation in bacterial number of eroded soil surface was noticed. Kuron, Glathe and Homrighausen (1959) investigated the utility of Rohagit S 7366 (methyl acrylate) a chemical meant for improvement of the soil. The structure of the soil showed improvement. This could be ascertained by the fact that Rohagit treated soils had a higher bacterial content.

After having drawn the attention of the distinguished gathering to the vast amount of literature pertaining to the use of fluorescent microscopy in assessing the microbial population of the soil each time for different purposes, I feel it my duty to point out that at least for us in India it is absolutely essential to take up the challenge of finding out the potentialities of the Indian soil in regard to its microbial population. Only then we could be in a position to know its fertility index. Apart from that a continuous effort for its improvement through application of chemicals has to be taken up. Whether the chemicals applied have been effective or not could be easily checked from time to time by assessing the microbial population quantitatively with the help of fluorescent microscope. This could be a routine-analysis. This alone can certainly not be the answer, but at least it has its own importance. Alongwith quantitative microbial population estimates the work has got to be combined with the qualitative analysis of soil-microflora *i.e.*, identification of the various forms of bacteria, fungi and actinomycetes and also the analysis of the biochemical activities of all these forms.

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